On-Grid Study of Rooftop Solar PV Energy Production System with Four Different Faces

Alfin Sahrin[1,2*], Imam Abadi[2] and Ali Musyafa[2]
[1]*Politeknik Energi dan Mineral Akamigas, Cepu, Indonesia*
[2]*Department of Engineering Physics, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia*

Keywords: On-Grid System, Rooftop Solar PV, Power Production Solar PV.

Abstract: In an effort to achieve net-zero emissions by 2060 and a 23% renewable energy mix by 2025, the Indonesian government has implemented rooftop solar PV as one of their strategies. However, optimal power production from a solar PV rooftop is influenced by azimuth, declination, and slope angles, among other factors. This study aims to compare the power production generated by rooftop solar PV with four faces with an on-grid system. This research was carried out at the coordinates -7.1475S, 111.590E, and time zone 07, with a tilt angle of 12° azimuth 0° north. The installation of a solar PV rooftop is permanent and not obstructed by any shading. The power gain on the north face is 3.64 kWh/kWp/day, the east face is 3.55 kWh/kWp/day, the south face is 3.44 kWh/kWp/day, and the west face is 3.52 kWh/kWp/day. The east and west faces have the advantage of getting irradiance when the sunshine and sunset are earlier and about one hour later than the north and south faces. This study can be used as a recommendation to install a solar PV rooftop in the same place and can be developed in other areas.

1 INTRODUCTION

The energy transition is a shift away from fossil fuels and toward greater use of renewable energy. With the reduction of fossil energy and the need to be more environmentally friendly, it is necessary to encourage the use of renewable energy in various sectors. The potential for mixed energy is abundant in Indonesia, ranging from solar, hydropower, wind, and geothermal energy. Indonesia has set a target of 23% renewable energy mix by 2025. The government has made a number of efforts to accelerate the implementation of renewable energy projects on a small to large scale. Regulations that have been issued by the Indonesian government through the Ministry of Energy and Mineral Resources (MEMR) regarding rooftop solar power plants have strongly encouraged consumers to take advantage of rooftop solar installations (Tasrif, 2021).

Indonesia is a tropical area with two seasons: dry and rainy. The potential for rooftop solar PV that can be developed in Indonesia is up to 32.5 GW. The utilization is used for several sectors, including social (4.6 GW), government (0.3 GW), households (19.8 GW), business (5.9 GW), and industry (1.9 GW). Rooftop solar PV aims to reduce electricity bills from grid sources, obtain electricity from renewable energy sources, and contribute to reducing greenhouse gas emissions. Standardization, operating patterns, equipment, and supervision are needed for the rooftop solar PV system to maintain its system's reliability (Widodo, 2017). In the technical installation of rooftop solar PV, there are many ways and technologies for the installation to be optimal. Knowledge of the weather is needed to predict solar PV production (Malvoni et al., 2017). It explains the differences between on-grid and off-grid rooftop solar PV systems so you can weigh the benefits and drawbacks (Kumar et al., 2018) (Naqvi et al., 2021). The tilt and azimuth position factors will also affect the performance of rooftop solar PV (Singh et al., 2016). In addition, the influence of shadows will optimize the absorption of sunlight to be converted into electrical energy (Abdelaziz et al., 2021).

On-grid and off-grid systems are widely used in rooftop solar PV applications. The on-grid system is connected to the distribution network, and the off-grid system is not connected to the distribution network but uses batteries (U. Hassan et al., 2021). The shadow factor must be a concern because it can affect the instability of the resulting power gain. Shadows affect how much solar PV can absorb

Sahrin, A., Abadi, I. and Musyafa, A.
On-Grid Study of Rooftop Solar PV Energy Production System with Four Different Faces.
DOI: 10.5220/0012110200003680
In *Proceedings of the 4th International Conference on Advanced Engineering and Technology (ICATECH 2023)*, pages 186-194
ISBN: 978-989-758-663-7; ISSN: 2975-948X

radiation (Bernadette et al., 2021). The effect of tilt angle and azimuth is significant for energy balance production in solar PV systems. To optimize the tilt and azimuth angles, the researchers used a lot of solar trackers (Božiková et al., 2021). The solar tracker is built with a single-axis and a double-axis tracker (Mohaimin et al., 2018). Other researchers compared solar PV to fixed systems using a solar tracker. The results of this study indicate that solar PV with a tracking system produces a more optimal output power than the fixed system (Nguyen et al., 2017).

Solar PV tracker components consist of mechanical and electrical components, which will increase the cost to build. This case will add to the increasingly complex system, which will cause new problems. Problems will arise when the drive system requires a power supply. If the solar PV system has a small capacity, more energy will be used to drive the tracker system. A more serious issue can arise if the driver is manuvering the system and abruptly stops, resulting in an incorrect position of the solar PV and a loss of solar PV production (Matius et al., 2021).

This paper is a study of the performance and production capacity of solar PV on four faces, namely north, east, south, and west. This study needs to be done because the rooftop solar PV installation follows the fixed roof's position and direction. This study is expected to find the optimal face position for obtaining solar PV production according to the building coordinates.

2 LITERATUR REVIEW

2.1 Position and Trajectory of the Sun

On the amount of solar irradiation (Al Garni et al., 2018). In addition, the maximum output of solar PV is influenced by several factors, namely the tilt angle and the orientation of the PV module, which need to be considered when installing solar PV. The amount of light intensity is influenced by geographical location (latitude and longitude), season, landscape, and weather. Figure 1 shows the solar time and angle and shows that the latitude of the earth is limited by the equator at the 0° position. Earth will experience tropical conditions if it is in the region of 23.45° to -23.45°, which is the angle of the sun's position during the solar noon, depending on the date and day.

Based on horizontal coordinates, the direction of the sun's motion is influenced by the zenith angle, azimuth, and altitude (Soulayman & Hammoud, 2016).

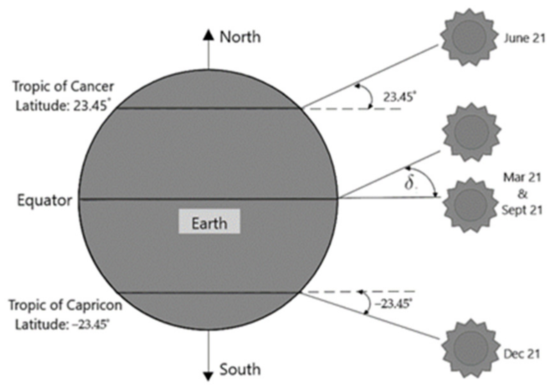


Figure 1: Solar declination angle.

The angle of the sun falling on the solar PV surface affects the light intensity per square. The more perpendicular the sun’s fall angle, the greater the intensity of light on the surface of the solar PV. Parameters to show the sun's fall angles are azimuth and altitude. Azimuth is the sun's declination based on the north direction. Azimuth is the angle formed by the direction from north to the point of projection of the sun to the horizon. The determination of the angle begins with a clockwise direction from north to east, south, west, and back north. Azimuth ranging from 0º to 360º degrees. Altitude is the angle formed between the observer's imaginary line and the sun's horizontal projection point with the vertical position of the sun. Altitude is often also called the height of the sun. Zenith is the perpendicular angle between the h observer's horizontal plane and the vertical plane for illustration as in Figure 2.

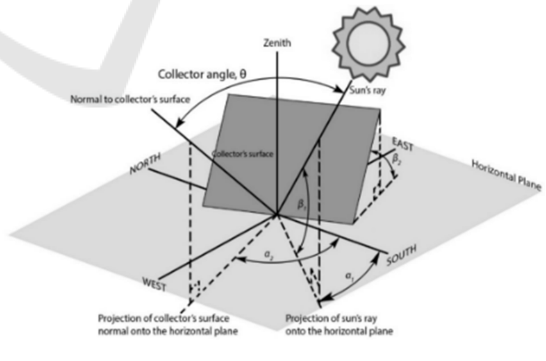


Figure 2: Illustration of zenith, azimuth and altitude angle.

2.2 Solar Cell Operating Characteristics

Solar cell performance can be characterized by the photocurrent-voltage curve (I-V). The measurement results of the I-V curve will produce several essential parameters for open-circuit photovoltage (Voc) and short-circuit photocurrent (Isc).

2.2.1 I-V Curve

A simple model to produce an I-V curve is to use a variable resistor. Measurements were made by irradiating the solar cells at a measured intensity (the standard test value of 1000 W/m2 at a temperature of 25 °C) under the standard test conditions. The results of the I-V curve for temperature changes can be seen in Figure 3.

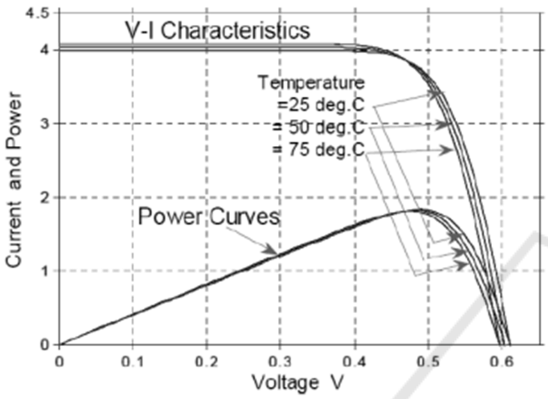


Figure 3: I-V curve with temperature variation (Mizard et al., 2019).

2.2.2 Solar Irradiation Variation

The intensity of light will affect the acquisition of solar energy. The rise and fall of light intensity will also affect the size of the output from the solar cell shown in Figure 4.

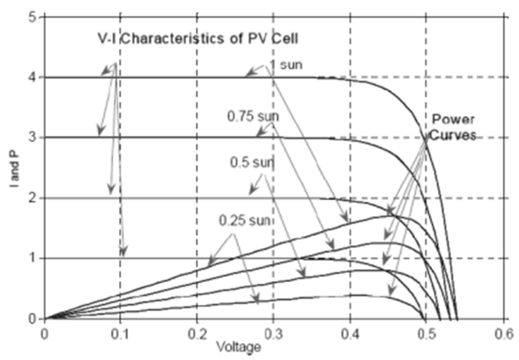


Figure 4: Solar irradiation variation.

2.3 Ongrid-Connected Solar PV System

Solar PV systems connected to the available utility lines are called "on-grid" systems. This study added an on-grid PV system with a battery for smoothing. Solar PV systems and utility grids serve as sources of electrical energy, and batteries serve as complementary energy storage systems to maintain stable output power. This system is connected to the utility network as a voltage and frequency reference. This system will stop operating when there is no connection to the utility network.

Figure 5 shows an on-grid solar PV system equipped with a battery. In this study, solar PV will be placed on four faces: north, east, south, and west. The four different positions will be examined for performance at the same time. The same solar PV capacity will produce different performances and characteristics in each direction. This performance will affect the load supply even with the same solar PV capacitance, weather conditions, and time.

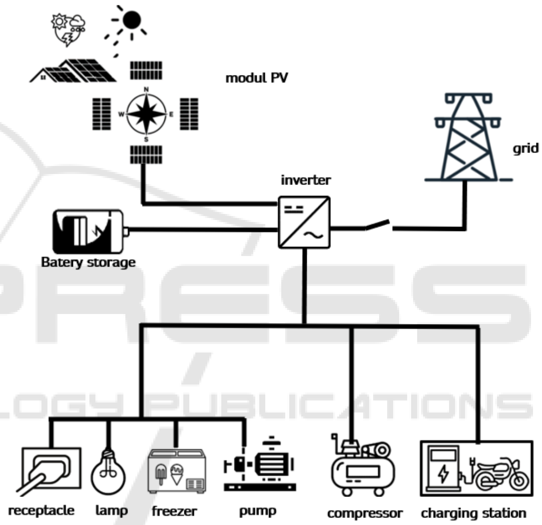


Figure 5: On-grid solar PV system.

2.4 Technical Analysis

The angle of declination is the angle of the sun when the sun is directly above the local position of an area for the equator. Positive value when for when the sun is in the north ($-23{,}45° \leq \delta \leq 23{,}45°$). The angle of declination can be given in equation 1.

$$\delta = 23{,}45° \, sin\left(\frac{N + 284}{365} \, x \, 360°\right) \qquad (1)$$

where N is the number of days in a year. 23.45 is the angle between the north and south latitudes. The angle is between 23.45° (north) and -23.45° (south). In addition, the earth's surface is also divided into latitude and longitude lines. The 0° latitude angle is on the Equator, and the 0° longitude angle is on the

Greenwich line. With 24 hours per day, 60 minutes per hour, and 1440 minutes per day, passing one-degree longitude takes 4 minutes.

Based on Figure 2, the angle of the solar PV is facing the southwest (0< α2 < 90° and β2 > 0°). β2 is a measure of the angle between the solar surface and the ground. θ is the angle between the sun and the normal reflection of the solar PV surface. The solar PV surface angle can be calculated by the radian angle in equation 2.

$$\cos\theta = \sin(\beta_1)\cos(\beta_2) + \cos(\beta_1)\sin(\beta_2)\cos(\alpha_1-\alpha_2) \quad (2)$$

It is critical to understand energy consumption when designing a solar PV system. Energy consumption, usually referred to as "load," describes energy consumption every hour, daily, monthly, and yearly. The calculation of energy consumption must be careful because it will affect the balance between supply and demand. In order to meet demand, the capacity of on-grid solar PV (PV_{cap}), the PV number capacity requirement (N_{pv}), and the number of inverter capacities (INV_{cap}) required for use in a solar PV system must be calculated. Battery requirements are also calculated to determine the number of batteries needed. The number of batteries needs to be considered between variations in load power requirements and the energy generated by solar PV at a certain time. Accurate battery calculations are expected to absorb and supply these variations. The battery position between the solar PV and the load is integrated with the inverter. The following equation can be used to calculate:

$$E_{ld} = \sum_{i=0}^{n} \frac{u_i \, x \, p_i \, x \, n_i}{1000} \quad kWh \quad (3)$$

$$PV_{cap} = \frac{E_{ld}(kWh)}{S_{rd}(kWh/m^2/day) \, x \, df(80\%)} \quad kW \quad (4)$$

$$N_{pv} = \frac{PV_{cap}(kW)}{P_{out}\,(Wp)} \quad (5)$$

$$INV_{cap} = 130\% \, x \, P_{peak}(kW) \quad kW \quad (6)$$

$$N_{batt} = \frac{E_{day} \, x \, \eta_d}{V_{bat} \, x \, I_h \, x \, DOD} \quad (7)$$

E_{ld} is a load of electrical energy needs (kWh), i is the load type as a lamp, the motor, etc. u_i is the number of hours per day on a device. p_i is powering each device. n_i is a number of devices.S_{rd} is the average of the matter radiation (kWh/m²/day), df is the landing factor with a magnitude (80%), P_{out} is the PV output power (Wp), and the power peak (P_{peak}) is the highest electrical power consumption (Jasuan et al., 2018). For the battery equation (N_{batt}) is the number of batteries required, (E_{day}) is daily consumed energy, (η_d) is the number of days required to reserve power, (V_{bat}) is the battery voltage rating, I_h is the ampere-hour rating, and (DOD) is deep of charge from the battery.

The design must consider several aspects to produce optimal energy and not have a lot of losses. The energy generated from solar PV flows to the load and is influenced by the PV output, inverter output, AC cable, and DC cable used.

Solar PV installation must also be considered in order to receive optimal sunlight. To maximize the amount of solar irradiation captured by solar PV, the face, direction, and tilt angle of the solar PV must be carefully considered. In addition, solar PV must be free from the shadows of objects.

The battery is an important component in this computer system. The battery is mounted on an on-grid system for smoothing purposes. The energy storage system is operating; the battery inverter acts as a load follower with the charge-discharge operation. When shading occurs in a PV system and causes the network frequency to drop, the battery will quickly replace power to stabilize the frequency as long as the battery's state of charge (SoC) is still above the minimum SoC. When the network frequency increases, excess energy from PV can be stored in the battery as long as the battery SoC is still below the maximum SoC. If the frequency is still not stable, the supply of solar PV will be reduced until the frequency becomes stable. In conditions of increasing or decreasing frequency, the utility company operates separately from the solar PV system because the battery response is faster than the generators on the utility grid.

3 MATERIAL AND METODOLOGY

Designing an on-grid solar PV system is very crucial. The determination of the selected material will affect the performance. The required energy consumption needs to be designed and calculated so the system can supply the load optimally. The materials selected in this study include the selection of solar PV modules, inverters, batteries, and loads. The following are some of the materials used:

3.1.1 Energy Consumption

The need for load consumption is calculated from the number of devices that work every day for 24 hours. Each device has a power capacity multiplied by the number of hours of daily energy consumption. The energy consumption of this system can be seen in Table 1.

Table 1: Energy consumption.

No	Appliance	Power (W)	Daily use (h/day)	Daily energy (Wh)
1	Lamp (LED/fluo)	10	10	600
2	Receptacle	175	10.5	913
3	Freezer	800	24	799
4	Pump	150	2	300
5	Compressor	200	2	400
6	Charging station	100	5	500

3.1.2 Solar PV Modules

This system uses 16 modules with a total design capacity of 3.5 kWp. Each module has a capacity of 250 Wp, arranged in a series of 8 pieces and 2 in parallel. The performance of the solar module system with a nominal PV power of 4.0 kWp, a maximum PV power of 3.8 kWDC, a nominal AC ratio of kWAC, and a Pnom ratio of 1.143 Installation requires an area of 26 m². Maximum operating voltage of 208 volts and a maximum current of 17.2 amps. The specifications and performance of the solar PV module system can be seen in Figure 6 and Table 2.

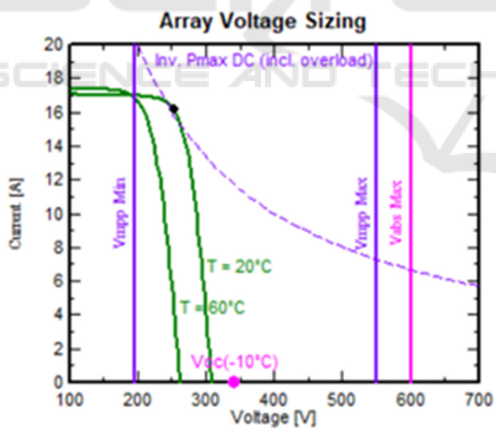


Figure 6: I-V curve performance characteristics.

Table 2: Solar PV module specification.

Parameters	Specification
PV module	Polycrystalline
Peak power capacity	250 Wp
Max. Voltage (Vmax)	30.95 V
Open circuit voltage (Voc)	37.89 V
Maximum current (Imax)	8.08 A
Short circuit current (Isc)	8.6 A
Size	1661 x 991 x 37
Efficiency	17.13%

3.1.3 Inverter

In this system, the inverter used is a hybrid-type inverter. The inverter has a capacity of 3.5 kW with a single-phase system that operates at a voltage of 195 to 550 volts with a frequency of 50 Hz. The number of inverters used is one that can be integrated with the grid line at a voltage level of 220 volts and a battery with a voltage of 48 volts. The specifications of the inverter used can be seen in Table 3.

Table 3: Inverter specification.

Parameters	Specification
Phase	1 Phase
DC power input maximum	3.70 kW
DC voltage input maximum	550 V
Grid voltage	230 V
AC power output nominal	3.5 kW
AC current output maximum	19 A
Frequency	50 Hz
Efficiency	95.3%

Table 4: Battery specification.

Parameters	Specification
Material	Lead-acid
Voltage	12 V
Capacity	100 Ah
Seri	4
Parallel	3
DOD	80%

3.1.4 Battery

When the solar PV system produces too much energy, the battery is used to store it. The number of batteries used in this system is 12 units, with a combination of 4 batteries in series and 3 in parallel. Each battery has a capacity of 300 Ah and a voltage of 12 V. The type of battery used is lead-acid, with an efficiency of up to 95.3%. The specifications of the battery used can be seen in Table 4.

3.1.5 Method

In this study, PVSys software was used to simulate the design results. The design includes the energy plan, solar PV power requirements, determining inverter capacity, and battery capacity. The capacity of the solar PV system in this study is 4.0 kWp, and the inverter capacity is 4.0 kWp. From this design, it is then deployed on software, including entering available geographic and climate data as shown in Table 5. This study was conducted at the latitude of -7.1475 S and longitude of 111.5906 E in a time zone

07, located in Cepu, Central Java. At that location, you will get power generated by the solar PV system when facing the north, east, south, and west cardinal directions. Figure 7 shows the flowchart simulation.

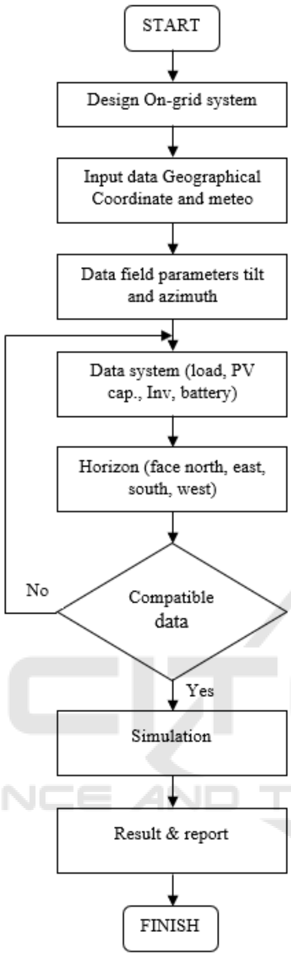


Figure 7: Flowchart.

4 RESULT AND DISCUSSION

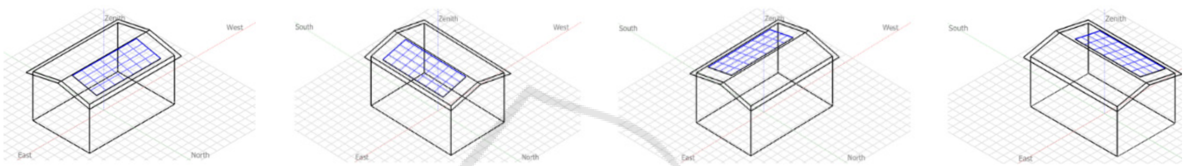
Based on this study, the simulation results that had been carried out produce several parameters for solar rooftop PV installed in different directions. The PV array system is placed on the rooftop in a fixed position at a tilt angle of 12° azimuth and 0° north. Solar rooftop PV systems have the same capability, from the total PV capacity to the installed load.

As shown in Figure 8, solar PV is deployed on the four faces. The rooftop position is fixed at a tilt angle of 12° according to the optimum tilt solar module data from the global solar atlas. Solar PV is exposed in different directions, facing north, east, south, and west. Power results on solar PV will be compared between positions. The power generated will vary according to the amount of solar irradiation captured by solar PV on different faces according to the trajectory of the sun at the declination angle. Different positions will be subject to shading according to the rooftop position and slope angle. Shading caused by the shape of the roof will affect the start and end of the time the solar PV generates power. The power generated by each face difference affects the performance ratio (PR). The performance ratio is defined as the ratio between the AC electrical energy produced by the generator and the results of theoretical calculations that will be produced by the generator if the module converts the received irradiance into electrical energy based on the generator capacity.

Based on Figure 9, depicts a shading diagram with various solar PV faces arranged differently. The diagram shows solar PV getting solar irradiation throughout the year, from January to December. In the north-facing position, the sun shines from March to September, not behind the horizon. Sun exposure can start at an azimuth angle of -70° to -90° with a sun height of 0° before 06.00. At sunset, it can also be optimal at an azimuth angle of 70° to 90° with a sun height of 0° around 18.00. In January, February, October, November, and December, the irradiation starts at the point of sunset behind the plane at an azimuth angle of -90° to -110° with a sun height of 5° before 06.00. at the time of sunset at an azimuth angle of 90° to 110° with a sun height of 5° before 18.00. On the east face, when the sun shines, there is no disturbance throughout the month from January to December. Irradiation starts at an azimuth angle of -70° to -110° with a sun height of 0° at 05.00. At sunset, it will accelerate at an azimuth angle of -70° to 110° with a sun height of 15° at 17.00. The south face is the opposite of the north face; from March to September, the sun's radiation is affected by the behind-the-plane effect at an azimuth angle of -70° to -90° with a sun height of 5° at 5.20. Sunset occurs at an angle of 70° to 90° with a sun height of 5° at 17.20. However, they do not experience it behind the plane when the sun or sunset starts in January, February, October, November, and December. The west-facing position is also the opposite of the east-facing position. The behind-the-plane problem occurs when the sunny conditions begin. From January to December, irradiation is obtained at an azimuth angle of -70° to -110° with a sun height of 15° at 06.00. At sunset, it can be maximized at an azimuth angle of 70° to 110° with a sun height of 0° at 18.00.

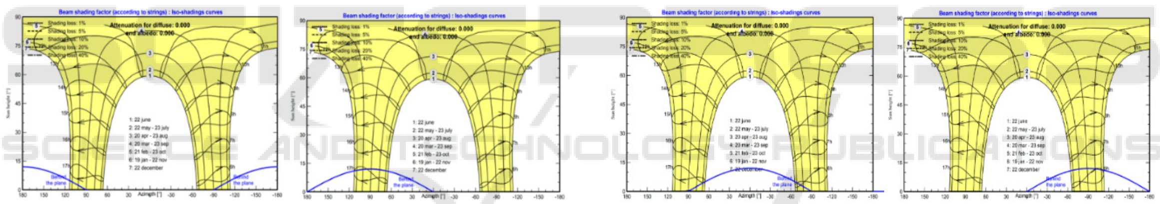
Table 5: Geographic and climate parameters.

Month	GlobHor kWh/m²	DiffHor kWh/m²	Temperature °C	Wind velocity m/s	Linke turbidity [-]	Relative humidity %
January	124.9	75.9	27.6	1.80	4.331	80.6
February	119.5	81.7	27.3	2.30	4.409	81.9
March	146.7	92.5	27.7	1.29	4.576	80.8
April	144.8	71.8	28.2	1.39	4.676	78.9
May	159.6	70.9	28.6	1.71	4.350	74.7
June	154.6	56.1	27.8	1.90	4.251	73.9
July	162.5	62.4	27.8	2.19	4.142	69.6
August	173.0	72.5	27.9	2.39	4.449	67.0
September	174.2	79.5	28.3	2.29	4.795	67.5
October	173.5	95.1	29.2	2.00	6.025	68.5
November	184.9	86.3	28.5	1.39	6.326	75.7
December	137.3	84.9	28.0	1.29	5.064	78.8
Year	1855.5	929.6	28.1	1.8	4.783	74.8



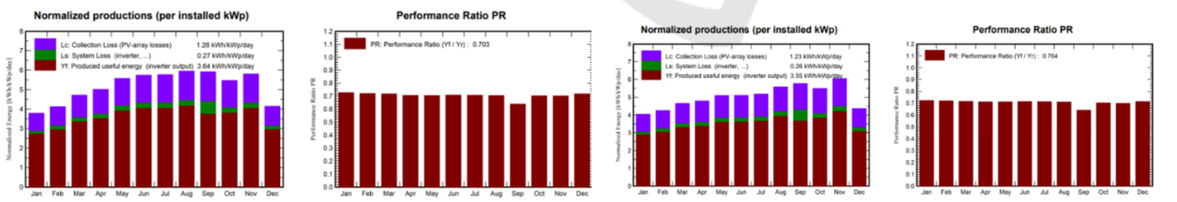
a. North face. b. East face. c. South face. d. West face.

Figure 8: Face solar PV.

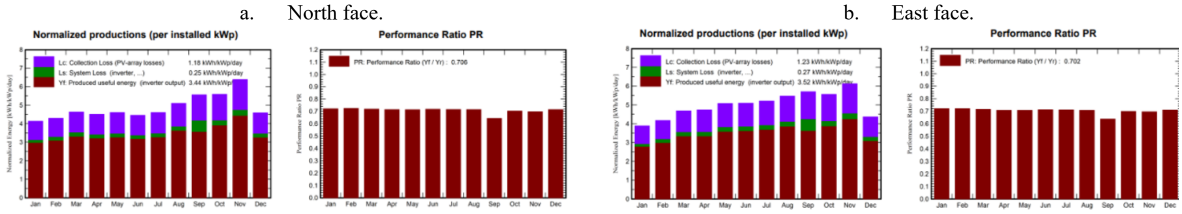


a. North face. b. East face. c. South face. d. West face.

Figure 9: Shading diagram.



a. North face. b. East face.



c. South face. d. West face.

Figure 10: Power production and performance ratio.

Based on Figure 10, a graph of power production and performance ratio has been shown on each face. The graph shows data per year, starting from January to December. On the north face, the production used is 3.64 kWh/kWp/day, with losses in the PV array and inverter of 1.26 kWh/kWp/day and 0.27 kWh/kWp/day. The lowest performance ratio was in September, with a value of 0.703. On the east face, the production used is 3.55 kWh/kWp/day, with losses in the PV array and inverter of 1.23 kWh/kWp/day and 0.26 kWh/kWp/day. The lowest performance ratio was in September, with a value of 0.704. On the south face, the production used is 3.44 kWh/kWp/day, with losses in the PV array and inverter of 1.18 kWh/kWp/day and 0.25 kWh/kWp/day. performance ratio with a value of 0.706 and the lowest occurring in September. On the west face, the production used is 3.52 kWh/kWp/day, with losses in the PV array and inverter of 1.23 kWh/kWp/day and 0.27 kWh/kWp/day. performance ratio with a value of 0.706 and the lowest occurring in September.

5 CONCLUSIONS

This study shows a comparison of four different ways of laying solar PV on different rooftops with the same tilt angle. Based on the simulation and analysis results, there are interesting things for further study. From the results of the analysis, the north face had the largest production at 3.64 kWh/kWp/day, followed by the east face at 3.55 kWh/kWp/day, the west face at 3.52 kWh/kWp/day, and the south face at 3.44 kWh/kWp/day. The east and west faces have the advantage of getting irradiance when the sunshine and sunset are earlier and about one hour later than the north and south faces. The highest performance ratio is 0.706 on the south face, and the lowest is 0.702 on the west face. On each face, the monthly low occurs in September.

REFERENCES

Abdelaziz, G., Hichem, H., Chiheb, B. R., & Rached, G. (2021). Shading effect on the performance of a photovoltaic panel. *2021 IEEE 2nd International Conference on Signal, Control and Communication (SCC)*, 208–213. https://doi.org/10.1109/SCC53769.2021.9768356

Al Garni, H. Z., Awasthi, A., & Ramli, M. A. M. (2018). Optimal design and analysis of grid-connected photovoltaic under different tracking systems using HOMER. *Energy Conversion and Management*, *155*, 42–57. https://doi.org/10.1016/j.enconman.2017.10.090

Bernadette, D., Twizerimana, M., Bakundukize, A., Jean Pierre, B., & Theoneste, N. (2021). 9. Analysis of Shading Effects in Solar PV System. *International Journal of Sustainable and Green Energy*, *10*(2), 47. https://doi.org/10.11648/j.ijrse.20211002.13

Božiková, M., Bilčík, M., Madola, V., Szabóová, T., Kubík, Ľ., Lendelová, J., & Cviklovič, V. (2021). The Effect of Azimuth and Tilt Angle Changes on the Energy Balance of Photovoltaic System Installed in the Southern Slovakia Region. *Applied Sciences*, *11*(19), 8998. https://doi.org/10.3390/app11198998

Jasuan, A., Nawawi, Z., & Samaulah, H. (2018). Comparative Analysis of Applications Off-Grid PV System and On-Grid PV System for Households in Indonesia. *2018 International Conference on Electrical Engineering and Computer Science (ICECOS)*, 253–258. https://doi.org/10.1109/ICECOS.2018.8605263

Kumar, N. M., Subathra, M. S. P., & Moses, J. E. (2018). On-Grid Solar Photovoltaic System: Components, Design Considerations, and Case Study. *2018 4th International Conference on Electrical Energy Systems (ICEES)*, 616–619. https://doi.org/10.1109/ICEES.2018.8442403

Malvoni, M., De Giorgi, M. G., & Congedo, P. M. (2017). Forecasting of PV Power Generation using weather input data-preprocessing techniques. *Energy Procedia*, *126*, 651–658. https://doi.org/10.1016/j.egypro.2017.08.293

Matius, M. E., Ismail, M. A., Farm, Y. Y., Amaludin, A. E., Radzali, M. A., Fazlizan, A., & Muzammil, W. K. (2021). On the Optimal Tilt Angle and Orientation of an On-Site Solar Photovoltaic Energy Generation System for Sabah's Rural Electrification. *Sustainability*, *13*(10), 5730. https://doi.org/10.3390/su13105730

Mizard, A. N., Aryani, D. R., Verdianto, A., & Hudaya, C. (2019). Design and Implementation Study of 3.12 kWp on–Grid Rooftop Solar PV System. *2019 International Conference on Electrical Engineering and Informatics (ICEEI)*, 465–470. https://doi.org/10.1109/ICEEI47359.2019.8988862

Mohaimin, A. H., Uddin, M. R., & Law, F. K. (2018). Design and Fabrication of Single-Axis and Dual-Axis Solar Tracking Systems. *2018 IEEE Student Conference on Research and Development (SCOReD)*, 1–4. https://doi.org/10.1109/SCORED.2018.8711044

Naqvi, A. A., Bin Nadeem, T., Ahmed, A., & Ali Zaidi, A. (2021). Designing of an off-grid Photovoltaic system with battery storage for remote location. *TECCIENCIA*, *16*(31), 15–28. https://doi.org/10.18180/tecciencia.2021.31.2

Nguyen, X.-T., Nguyen, V.-D., Nguyen, D.-Q., Nguyen, L.-T., & Nguyen, D.-Q. (2017). Performance comparison between tracking and fixed photovoltaic system: A case study of Hoa Lac Hi-tech Park, Hanoi. *2017 International Seminar on Intelligent Technology and Its Applications (ISITIA)*,128–133. https://doi.org/10.1109/ISITIA.2017.8124067

Singh, H., Sirisamphanwong, C., & Santhi Rekha, S. M. (2016). Effect of Tilt and Azimuth Angle on the Performance of PV Rooftop System. *Applied*

Mechanics and Materials, *839*, 159–164. https://doi.org/10.4028/www.scientific.net/AMM.839.159

Soulayman, S., & Hammoud, M. (2016). Optimum tilt angle of solar collectors for building applications in mid-latitude zone. *Energy Conversion and Management*, *124*, 20–28. https://doi.org/10.1016/j.enconman.2016.06.066

Tasrif, A. (2021). *Ministry of Energy and Mineral Resources Regulation No 26 of 2021*. Ministry of Energy and Mineral Resources.

U. Hassan, M., Saha, S., & Haque, M. E. (2021). 8. A framework for the performance evaluation of household rooftop solar battery systems. *International Journal of Electrical Power & Energy Systems*, *125*, 106446. https://doi.org/10.1016/j.ijepes.2020.106446

Widodo, J. (2017). *Regulation of The President of the Republic of Indonesia No 22 of 2017*. RI Cabiner Secretariat.