Optimization of The Azimuth Direction and Tilt of The Campus Cafe Rooftop Solar Panels

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Abstract. Countries located on the equator have relatively high intensity of solar radiation. The thing that is most needed in a solar power plant is the intensity of solar radiation. Based on this, Indonesia is very suitable for the application of solar power plants. The power generated by a solar power plant is directly proportional to the intensity of the solar radiation received by solar panels. To maximize the intensity of solar radiation received by solar panels, it is necessary to design the azimuth and tilt directions of installing solar panels on the roof of a building. This study discusses the influence of the azimuth direction and the tilt of the installation of solar panels on the intensity of solar radiation received in a building on the campus environment. The method used to obtain the most optimal energy production is to use a combination of azimuth direction and solar panel tilt. Daily sunshine data is simulated via HelioScope. The findings indicated that the best energy generation results were achieved by blending an azimuth angle of 20o with a tilt angle of 30o. In this combination of angles, an energy production of 28.9 kWp is obtained.

Keywords: HelioScope, Solar Power Plant, Solar irradiation, Tilt, Azimuth.

1. Introduction

The development of the electric network is currently growing rapidly. Initially, it only relied on the supply of electricity from large power plants and used coal as a source of power, or what is commonly known as a steam power plant. Then developed the generation of electricity with water power, wind power, and solar power which is included in the renewable energy group [1].

Given the increasing demand for energy globally, the use of various renewable energy sources is the right solution to deal with the global energy crisis. Solar energy is the largest renewable energy that can be enjoyed compared to other renewable energy sources such as wind energy, geothermal energy, biomass energy and water energy [2, 3].

The needs of today's electricity users besides requiring electrical energy, have also implemented environmentally friendly concepts or green buildings. Generators using wind power or solar power are excellent in the application of environmentally eco-friendly power

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plants [4]. The use of renewable energy such as solar energy which is abundantly available in most parts of the world is needed to overcome the problems faced due to environmental damage due to global warming [5]. Optimization of solar power plants can be used to reduce carbon dioxide (CO2) emissions [6, 7]. The potential for cost reduction and grid balance could make photovoltaic (PV) one of the most important energy sources in the future [8].

The working principle of PV is that it can convert solar energy into electrical energy. The important point here is that solar energy is only obtained as long as the sun is shining. Solar energy needs to be stored for use when there is no sun. In addition to electrical energy, solar energy also has many other uses such as space heating, water heating, dryers, solar pumps, etc. [9]. This goal can be achieved either by connecting the power system to a grid or using the batteries [10].

The result is many countries are shifting their focus to this energy source. However, solar energy has dependencies on environmental and meteorological factors [11]. Photovoltaic system has main factors that affect solar photovoltaic performance, namely radiation, temperature, and soil conditions around the solar panel [12, 13].

Countries located on the equator have relatively high intensity of solar radiation. The thing that is most needed in a solar power plant is the intensity of solar radiation [14]. Indonesia is a country located on the equator. Based on this, Indonesia is very suitable for the application of solar power plants [15, 16].

The solar power generation system has two design forms, namely the fixed design and the sun tracking design. Compared to the fixed design, solar tracking has a higher energy conversion efficiency and a higher cost as well [17].

The main problem with solar power plants is the level of solar radiation and the temperature around the solar cell which cannot be obtained consistently. The power generated by a solar power plant is directly proportional to the intensity of the solar radiation received by the solar panels. The greater the intensity of solar radiation received by solar panels, the greater the power production from solar power plants [15, 18]. The fact that solar energy available at a particular location is not same throughout the year as well it varies from different location [19].

In order for the intensity of solar radiation received by solar panels to be maximized, it is necessary to find the azimuth direction and the slope of the installation of solar panels on the roof of a building. It is recommended that the installation of a photovoltaic system pay attention to the tilt of the solar panel module and its orientation. By making the right choices, we will achieve better performance and higher production [20, 18]. Several applications for optimizing the use of solar energy use the sun tracking system method with azimuth elevation and this is one of the most popular methods. [21].

The structure and orientation of the roof affect the placement of the rooftop solar power plant. Roof orientation and slope determine the possible azimuth and tilt angles for solar panel installations [16, 17]. It is generally recommended to install solar panels facing south for installation locations in the Northern Hemisphere and facing north for installation locations in the Southern Hemi-sphere [21]. The azimuth direction is the direction that uses the south direction as a reference. Meanwhile, the slope of the solar panel installation is the angle formed with the horizontal plane of the roof of the building [22].

Several buildings that usually use very large electrical energy are office and commercial buildings. The amount of costs that must be incurred is directly proportional to the use of electrical energy [23]. This study discusses the influence of the azimuth direction and the tilt of the installation of solar panels on the intensity of solar radiation received in a building on the campus environment. suitable.

2. Methods

This research was conducted to determine the design of the slope and direction of installing solar panels on a building in the Muhammadiyah University of Semarang, Indonesia. The first step is to look for software PV optimization. Researchers used the help of HelioScope software to collect radiation and temperature data around solar panels.

The HelioScope software was designed by Folsom Labs. HelioScope is a solar photovoltaic simulator with world-class features. HelioScope assists researchers in the design and technical process of solar power simulation by combining performance modelling and solar panel layout.

HelioScope can generate classy solar layouts and performance estimates for anyone with access to them. The features of HelioScope are similar to similar simulator applications and add design features in CAD form. The main input for the operation of HelioScope requires location address data, PV module type, and inverter specifications [24].

The software allows researchers to estimate energy production that takes climate and weather losses into account. The efficiency of components, panel wiring, and shading can also be analysed to find recommended values for the layout of the array and equipment. HelioScope is a web-based simulator, so there's no need to install software. HelioScope can be used from any connected computer. The software displays data sets of weather, annual production, and performance ratios of solar cell systems. Use of HelioScope can subscribe on a monthly or yearly basis to get all the features that this software has [25].

Subsequently, the outcomes from the HelioScope software simulation are assessed by taking into account changes in the solar panel tilt angle with respect to the building's roof and variations in the azimuth angle. Variation of slope in this study from 10o to 30o. The azimuth variation in this study is from 10o to 180o.

The collected data are analysed to find the correlation between azimuth and tilt variation with PV energy can produced. After find the optimum setting of variation azimuth and tilt for the PV system, next step is calculating the electrical efficiency of the optimum setting. The PV module's electrical efficiency is:

$$\eta_e = \frac{\text{Produced electrical power}}{\text{Total received energy}} = \frac{E_p}{E_{in}} \quad (1)$$

The building used as the object of this research simulation is a campus café building which consists of two floors. The choice of campus cafes as research objects is because these buildings are not as big as lecture buildings so it is possible to use solar power plants as the main source of electricity.

3. Result and Discussion

The results of the research on the influence of the direction of azimuth setting and the slope of the solar panel can be seen in Table 1. The variation of the azimuth angle tested in the study was from an azimuth angle of 10° to an azimuth angle of 180°. At various variations of the azimuth angle it was also tested for the inclination angle of the solar panel installation to the horizontal media starting from the tilt angle of 10° to 30°. The slope angle is limited to 30° because this slope is adjusted to the slope of the roof.

Table 1. Energy Production with Variation Azimuth and Tilt (kWp)

Azimuth (°)	Tilt 10°	Tilt 20°	Tilt 30°
10	22.3	23.1	24.5
20	23.6	27.6	28.9
30	22.3	23.1	24.9
40	20.9	22.7	24.0
50	21.8	22.7	24.0
60	19.6	21.4	24.5
70	22.3	22.7	23.6
80	19.1	19.6	20.9
90	20.9	21.4	22.3
100	21.4	22.3	23.6
110	22.7	22.7	24.0
120	21.4	22.7	23.6
130	20.5	20.9	22.3
140	18.7	19.6	20.9
150	21.8	22.7	24.0
160	22.3	23.1	24.5
170	21.4	21.8	23.1

Azimuth (°)	Tilt 10°	Tilt 20°	Tilt 30°
180	21.8	22.7	23.6

In various variations of azimuth and tilt, the most optimal energy production results are obtained at the combination of an azimuth angle of 20° and a tilt angle of 30°. The minimum energy production results are obtained from a combination of an azimuth angle of 140° and a tilt angle of 10°.

Table 2. Energy Production Nameplate Projection with Variation Azimuth and Tilt (MWh)

Azimuth (°)	Tilt 10°	Tilt 20°	Tilt 30°
10	38.771	40.334	40.910
20	41.091	48.085	49.245
30	38.744	40.237	42.371
40	36.327	39.342	40.682
50	37.767	39.138	40.499
60	33.793	36.643	40.907
70	38.249	38.702	39.122
80	32.757	33.104	34.331
90	35.620	35.803	36.072
100	36.203	36.905	37.689
110	38.257	37.270	37.750
120	35.823	36.851	36.393
130	34.162	33.582	33.712
140	31.060	31.122	31.132
150	36.119	35.735	35.206
160	36.713	36.168	35.320
170	35.163	33.871	33.053
180	35.841	35.162	33.494

From table 2 we can conclude that the most projected energy production based on the arrangement of solar panels is at the combination of an azimuth angle of 20° and a tilt angle of 30°. The results in table 2 were obtained within 1 year.

Table 3. Energy Production Received with Variation Azimuth and Tilt (MWh)

Azimuth (°)	Tilt 10°	Tilt 20°	Tilt 30°
10	31.301	32.485	33.009
20	33.034	38.585	39.821
30	31.255	32.375	34.284
40	29.190	31.563	32.721
50	30.394	31.422	32.559
60	27.291	29.462	32.963
70	30.876	31.082	31.416

Azimuth (°)	Tilt 10°	Tilt 20°	Tilt 30°
80	26.335	26.731	27.585
90	28.710	28.895	29.181
100	29.220	29.865	30.394
110	30.865	30.100	30.582
120	28.960	29.809	29.497
130	27.681	27.181	27.508
140	25.027	25.356	25.372
150	29.275	29.032	28.801
160	29.812	29.462	28.991
170	28.506	27.617	27.135
180	29.076	28.651	27.470

From table 3 we can conclude that the most energy production can be received by grid based on the arrangement of solar panels is at the combination of an azimuth angle of 20° and a tilt angle of 30°. The efficiency of solar panels can be calculated by dividing the results in table 3 with the results in table 2 according to formula (1). For example, in table 3 for the combination of an azimuth angle of 20° and a tilt angle of 30° an energy of 39,821 MWh is obtained and in table 2 for the same variation an energy of 49,245 MWh is obtained, so that efficiency is obtained by 80.86%. All variations produce the same efficiency value because they use the same type of solar panel. The top view of the solar panel placement design with a combination of an azimuth angle of 20° and a tilt angle of 30° can be seen in Figure 3.

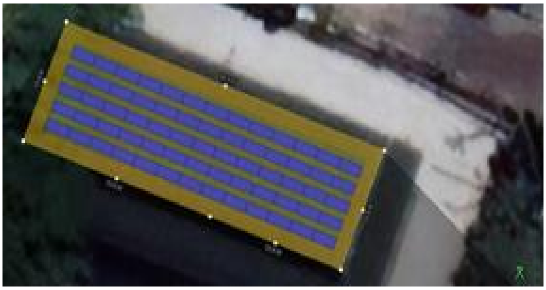

Fig 1. Top view of the solar panel placement design with an azimuth of 20° and a tilt of 30°.

In Figure 1 it can be seen that solar panels can be optimally placed in neat rows because at this azimuth angle solar panels that are rectangular can be placed parallel to the shape of the rectangular building as well. The top view of the solar panel placement design with a combination of an azimuth angle of 140° and a tilt angle of 10° can be seen in Figure 4.

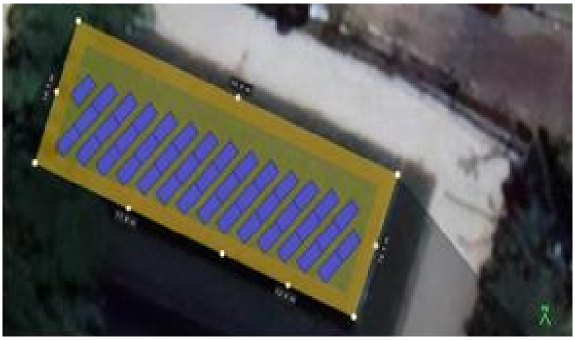

Fig 2. Top view of the solar panel placement design with an azimuth of 140° and a tilt of 10°.

In Figure 2 it can be seen that the solar panels cannot be optimally placed be-cause at this azimuth angle the rectangular solar panels form a large enough angle with the rectangular shape of the building as well. A side view of the solar panel placement design with a combination of an azimuth angle of 20° and a tilt angle of 30° can be seen in Figure 5.

Fig 3. Side view of the solar panel placement design with an azimuth of 20° and a tilt of 30°.

In Figure 3 you can see the position of the tilt of the solar panel facing north. In this position, the solar panel faces the direction of solar energy so that the resulting energy production is most optimal. A side view of the solar panel placement design with a combination of an azimuth angle of 140° and a tilt angle of 10° can be seen in Figure 6.

In Figure 4 you can see the position of the tilt of the solar panel facing north and east. In this position, the solar panel does not face the direction of solar energy so that the resulting energy production cannot be optimal.

Fig 4. Side view of the solar panel placement design with an azimuth of 140° and a tilt of 10°.

From optimum setting with a combination of an azimuth angle of 20° and a tilt angle of 30°, the system can produce 28.9 kWp of electrical energy. Nameplate energy can be produced by module PV system is 49.245 MWh with total received energy annually 39.821 MWh. So, the system has electrical efficiency 80.86% with this optimum setting.

4. Conclusion

Energy production from solar power plants can be optimal if it approaches or matches the angle of the sun's rays. The method for approaching the angle of arrival of sunlight can use optimization of the azimuth angle setting and setting the angle of inclination of the solar panel to the horizontal plane. This study reaches the conclusion that the most favorable energy generation results are achieved through the combination of a 20° azimuth angle and a 30° tilt angle. This combination produces 28.9 kWp of electrical energy. The combination of azimuth and tilt angles in the study could be different if applied in another place which is quite far from the research location because for each location that is not close together the combination of azimuth and tilt angles will be different. In this study, from long-term view, the results of the study revealed the relationships in PV performances based on solar irradiance and solar energy.

Authors' Contributions

Author 1 developed the theoretical formalism, carried out the design and carried out simulations. Author 2 contributed to detailed of the article. Both Author 1 and Author 2 contributed to the final version of the manuscript.

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References

1. R. Siahaan, I. W. Kusuma, and I. B. Adnyana, "Pengaruh Sudut β dan ω pada PLTS di PT. Indonesia Power," METTEK, vol. 6, no. 1, pp. 62–69, 2020.
2. A. Barbon, M. Ghodbane, L. Bayon, and Z. Said, "A general algorithm for the optimization of photovoltaic modules layout on irregular rooftop shapes," J. Clean. Prod., vol. 365, 2022.
3. I. P. dos Santos and R. Ruther, "Limitations in solar module azimuth and tilt angles in building integrated photovoltaics at low latitude tropical sites in Brazil," Renew. Energy, vol. 63, pp. 116–124, 2014.
4. A. Shrivastava, R. Sharma, M. K. Saxena, V. Shanmugasundaram, M. L. Rinawa, and Ankit, "Solar Energy Capacity Assesment and Performance Evaluation of A Standalone PV System Using PVSYST," Mater. Today Proc., 2021.
5. M. M. Rahman, M. Hasanuzzamana, and N. A. Rahim, "Effects of Operational Conditions on The Energy Efficiency of Photovoltaic Modules Operating in Malaysia," J. Clean. Prod., vol. 143, pp. 912–924, 2017.
6. I. Nawaz and G. N. Tiwari, "Embodied Energy Analysis of Photovoltaic (PV) System based on Macro and Micro-Level," Energy Policy, vol. 34, no. 17, pp. 3144–3152, 2006.
7. L. M. Ayompe, A. Duffy, S. J. McCormark, and M. Conlon, "Measured Performance of a 1.72 kW Rooftop Grid Connected Photovoltaic System in Ireland," Energy Convers. Manag., vol. 52, no. 2, pp. 816–825, 2011.
8. D. Gielen, F. Boshell, D. Saygin, M. D. Bazilian, N. Wagner, and R. Gorini, "The Role of Renewable Energy in The Global Energy Transformation," Energy Strateg. Rev., vol. 24, pp. 38–50, 2019.
9. C. P. Mohanty et al., "Parametric Performance Optimization of Three Sides Roughened Solar Air Heater," Energy Source Part A, vol. 24, 2020.
10. Rekhashree, J. S. Rajashekar, and H. Naganagouda, "Study on Design and Performance Analysis of Solar PV Rooftop Standalone and On Grid System Using PVSYST," Int. Res. J. Eng. Technol., vol. 05, no. 7, pp. 41–48, 2018.

11. I. Daut, F. Zainudin, Y. M. Irwan, and A. R. N. Razliana, “Analysis of Solar Irradiation and Solar Energy in Perlis, Nothern of Peninsular Malaysia,” Energy Procedia, vol. 18, pp. 1421–1427, 2012.
12. K. Chiteka, L. Madiye, H. Chingosho, R. Arora, and C. C. Enweremadu, “A numerical modelling approach for the optimisation of photovoltaic installations in the mitigation of thermal effects,” Sci. African, vol. 16, 2022.
13. R. Nasrin, M. Hasanuzzamana, and N. A. Rahim, “Effect of Irradiation on Photovoltaic Power and Energy,” Int. J. Energy Res., pp. 1–17, 2017.
14. M. S. N. Rega, N. Sinaga, and J. Windarta, “Perencanaan PLTS Rooftop untuk Kawasan Pabrik Teh PT Pagilaran Batang,” ELKOMIKA, vol. 9, no. 4, pp. 888–901, 2021.
15. H. D.L. Pangestuningtyas and Karnoto, “Analisis Pengaruh Sudut Kemiringan Panel Surya Terhadap Radiasi Matahari Yang Diterima Oleh Panel Surya Tipe Larik Tetap,” TRANSMISI, vol. 2, no. 4, pp. 930–937, 2013.
16. R. Darussalam, A. Rajani, Kusnadi, and T. D. Atmaja, “Pengaturan Arah Azimuth dan Sudut Tilt Panel Photovoltaic untuk Optimalisasi Radiasi Matahari, Studi Kasus: Bandung-Jawa Barat,” in SNF2016, 2016, pp. 31–35.
17. L. Qi, M. Jiang, Y. Lv, and J. Yan, “A celestial motion-based solar photovoltaics installed on a cooling tower,” Energy Convers. Manag., vol. 216, 2020.
18. B. Belmahdi and A. El Bouardi, “Solar Potential Assessment Using PVSYST Software in the Northern Zone of Morocco,” Procedia Manuf., vol. 46, pp. 738–745, 2020.
19. N. M. Kumar, M. R. Kumar, P. R. Rejoice, and M. Mathew, “Performance Analysis of 100 kWp Grid Connected Si-Poly Photovoltaic System Using PVSYST Simulation Tool,” Energy Procedia, vol. 117, pp. 180–189, 2017.
20. J. M. Longares, A. Garcia-Jimenez, and N. Garcia-Polanco, “Multiphysics Simulation of Bifacial Photovoltaic Modules and Software Comparison,” Sol. Energy, vol. 257, pp. 155–163, 2023.
21. L.-V. Oon, M.-H. Tan, C.-W. Wong, and K.-K. Chong, “Optimization study of solar farm layout for concentrator photovoltaic system on azimuth-elevation sun-tracker,” Sol. Energy, vol. 204, pp. 726–737, 2020.
22. A. Merilainen, P. Puranen, A. Kosonen, and J. Ahola, “Optimization of rooftop photovoltaic installations to maximize revenue in Finland based on costumer class load profiles and simulated generation,” Sol. Energy, vol. 240, pp. 422–434, 2022.

23. Samsurizal, R. Afrianda, and A. Makkulau, "Optimizing The Potential of Solar Energy PT. PJB UP Muara Karang Rooftop Area Using HelioScope," J. Tek. Elektro ELKHA, vol. 14, pp. 1–6, 2022.

24. D. J. Damiri and A. A. Nugraha, "Technical Performance and Economic Feasibility Simulation of 200kWp Rooftop Solar Photovoltaic On Grid on Industrial Estate Factoty," J. Rekayasa Elektr., vol. 17, pp. 86–93, 2021.

25. M. S. Ali, N. N. Rima, M. I. H. Sakib, and M. F. Khan, "HelioScope based Design of MWp Solar PV Plant on A Marshy Land of Bangladesh And Prediction of Plant Performance With The Variation of Tilt Angle," GUB J. Sci. Eng., vol. 5, no. 1, pp. 1–5, 2019.