Comparison of PV Rooftop Energy Production at Denpasar City Office Building

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Abstract— The Indonesian government has made various targets for implementing renewable energy, one of which is the application of PV. PV rooftop in households and offices is one of the applications of PV that can be applied because people can contribute to achieving national energy targets by utilizing empty spaces on the roofs of buildings. Therefore in this paper will examine how the rooftop PV system is designed and how energy is produced, as well as the factors that affect energy production. PV rooftop in Denpasar city office building has two pilot projects that can be used as research objects that will be examined how much energy potential is simulated with the HOMER application. The rooftop PV in the two pilot projects will also determine how the orientation and slope angle of the PV module are optimum. From the simulation results show the energy potential in the two pilot projects is 3% and 39% greater than the actual energy. PV rooftop on both pilot projects has 20 ° PV slope, while the calculation results show an optimal slope is 15 °. The amount of energy produced can be affected by its less than optimal slope angle, the cleanliness of the modules that are not cleaned regularly, and the many weather conditions, rainy days and cloudy days, so that the sun is less than optimal.

Keywords— Renewable Energy, PV, PV Rooftop, Energy Production, Potential of PV Energy

I. INTRODUCTION

The application of Renewable Energy in Indonesia is still very small from the existing potential of 443.2 GW. The potential for renewable energy in Indonesia is only 2% of its potential. Solar energy is a renewable energy that has a huge potential energy of 207.9 GW, but the use of solar energy in Indonesia has only reached 0.04% of its potential. The development of solar power for electricity is projected at 6.5 GW in 2025 and 45 GW in 2050 [1].

PV rooftop can help the government in fulfilling the target of solar power utilization in Indonesia, where solar panels are placed on roofs of houses or offices so that they can utilize the empty spaces on the roof to get solar energy that can be converted into electrical energy. Urban communities in Indonesia also have quite good characteristics in the use of PV such as purchasing power, level of education, and understanding of the environment and its protection. In Indonesia there is also the availability of PV components to support the PV rooftop, the constraints of the slow progress of this development because the main components of PV are solar panels that still get these products from other countries [2]. The government has also made regulations to support the development of PV in Indonesia for the realization of renewable energy targets and

attract the public in utilizing rooftop PV. PLN's Directors Regulation No. 0733.K / DIR / 2013 allows people to sell electrical energy produced by rooftop PV to the State Electricity Company (PLN) [3].

PV in Indonesia will be built a lot, especially PV rooftop in achieving the 6.5 GW target in 2025. Therefore, PV rooftop information is needed for people who will install PV rooftop so they can contribute in the development of PV. These information are the technical design of PV, Potential energy production of PV, energy production from installed PV, and factors that affect PV energy production. This information is expected to help people to contribute in building PV at home or in their offices.

PLN Distribusi Bali in the city of Denpasar has installed two PV rooftop that can be used as pilot projects, that is in the PLN Distribusi Bali building (Building # 1) and in the PLN Area Bali Selatan building (Building # 2). Building # 1 is installed with a 30kW rooftop PV with a number of 120 units of modules, each module has an output power of 250W, inverter used is two units with a capacity of each inverter of 20kW. In Building # 2 there is a 10kW rooftop PV with a number of 38 unit modules, each module has an output power of 265W, with one inverter unit used with a capacity of 10kW. Both pilot projects do not use battery backup and directly connected to the grid.

This study will examine both the rooftop PV pilot projects in Building # 1 and Building # 2 by simulating the installed PV to get the energy potential that is simulated with the HOMER software. The study also determines the orientation and slope angle of the PV to be analyzed to find out about the PV rooftop technical design, the PV rooftop potential energy produced, energy production of installed PV rooftop, and factors that affect the PV rooftop energy production. These information about PV rooftop is not available yet in Indonesia even though this information is very important to be known by the Indonesian people. This information is also expected to attract that people to participate in installing rooftop PV for the realization of the national energy that has been targeted.

II. METHODOLOGY

The data used in this study are documentation, environmental conditions, monitoring data recorded on PV installed in Building # 1 and Building # 2, single line diagrams, location data and weather data from the Climatology and Geophysics Meteorology Agency (BMKG).

The maximum efficiency of the solar panel will increase if the angle of sunlight is always at 90° to the panel surface. But in reality the incident of solar radiation varies based on latitude and declination of the sun for a year. In fact the Earth's rotational axis has a slope of about 23.45° to the plane of the Earth's orbit by the sun, at certain latitudes high from the sun in the sky varies every day. To find out the maximum height of the sun (in degrees) when the sun reaches the sky (α), it is easy to use the following formula [4]:

$$\alpha = 90^\circ - \text{lat} + \delta \text{ (N hemisphere)} \quad (1)$$

$$\alpha = 90^\circ + \text{lat} - \delta \text{ (S hemisphere)} \quad (2)$$

Where, Lat is the latitude (latitude) of the PV location that is installed (in degrees) and δ is the angle of the sun's declination (23.45°).

If the angular angle of the maximum height of the sun (α) is known, then the slope of the PV module (β) can also be known. But it is not enough to just know α to determine the optimal orientation of the PV module, while the angle that must be formed by the PV module against the earth's surface (β), can be obtained by:

$$\beta = 90^\circ - \alpha \quad (3)$$

To get potential energy production in PV installations can be done with a professional simulation program [5]. HOMER is software that is used to help modeling of an electric power system by using a variety of renewable resources [6].

PV orientation in the case of PV rooftop can be obtained by using the compass application on a smartphone that provides a map from Google so that we can see the image of the upper part of the building from the Google satellite and get the results in which direction the roof of the building is facing [7].

The roof orientation is obtained by entering the address where the building was built on Google Maps, after that there will be a compass image that shows the cardinal direction of Google Maps, and there is an axis in the center of the compass that shows the orientation where the observer / building is facing, after that place the axis on the application to the axis of the building that wants to know its orientation, after that we get in the direction of the orientation of the building.

The slope angle for rooftop PV, especially the pitched roof usually tends to follow the slope of the roof, in this case to find out how the slope of the PV can be measured by using a smartphone application that can do angle measurements equipped with angle measurement features via camera or image such as the Pitch Gauge application, Angle Meter Pro, Smart Protactor [8]. The slope measurement is done by calibrating the smartphone where the 0° angle is parallel to the roof base (Run / Span), then the smartphone is tilted to follow the slope of the roof captured by the camera and the measurement results are displayed on the screen.

Research on the production of PV rooftop energy in Building # 1 and PV rooftop in Building # 2 is carried out with the following steps:

Figure 1. Research Diagram

III. RESULT AND DISCUSSION

A. Technical Design PV Rooftop Building #1

Building #1 located at Jl. Letda Tantular No.1, Dangin Puri Klod, Denpasar Timur, Kota Denpasar, Bali.

Figure 2. PV Rooftop at Building #1

Building # 1 installed PV rooftop with a capacity of 30kW, installed since May 2017 and starting operation in June 2017. PV rooftop Building # 1 is an on-grid PV that supplies electrical energy to the office and gets additional electricity supply from the grid if the PV is not enough to fill the load.

Figure 3. Line Diagram PV Rooftop at Building #1

PV rooftop in Building # 1 is a PV with the system connected to the grid (On-Grid). PV rooftop in Building # 1 has a power capacity of 30 kWp, which is produced from 120 Perlight PLM-260p-60 series PV modules with the power of each PV module is 250 Wp. The entire PV module is divided into 2 arrays, each array consisting of 60 modules connected in series and parallel. Electrical energy produced by one group of PV arrays will be distributed first through the combiner panel. After going through the combiner panel, electrical energy in the form of direct current will be converted by the SPI20K-B Series Kehua Tech inverter into alternating current to pass through the AC distribution panel. The AC distribution panel will distribute the PV energy to the office load (690 kVA) which will get a back-up from the grid if the energy produced by PV is not enough to fill the office load.

B. Technical Design PV Rooftop Building #2

Building # 2 located at Jl. P.B. Sudirman No.2, Dauh Puri, Denpasar Barat, Kota Denpasar, Bali. Building # 2 is installed with PV rooftop with a capacity of 10kW, installed since the beginning of January 2017 and starts operating in mid-January 2017. PV rooftop Building # 2 is an on-grid PV that supplies electrical energy to the office and gets

additional electricity supply from the grid if PV is not enough to fill the load.

Figure 4. PV Rooftop at Building #2

Figure 5. Line Diagram PV rooftop at Building #2

PV rooftop in Building # 2 is a PV with a grid-connected system (On-Grid). PV rooftop in Building # 2 has a power capacity of 10 kWp, generated from 38 Canadian Solar CS6P-265P-SD PV modules with the power of each PV module is 265 Wp. The entire PV module is divided into 2 arrays, each array consisting of 19 modules connected in series.

The electrical energy produced by a group of PV arrays will be distributed first through to the DC isolator kit. After going through the DC isolator kit, the electrical energy in the form of direct current will be converted by the Growatt 10000UE inverter into an alternating current to the AC isolator kit to pass the AC distribution panel, which will then be distributed to the office load (197 kVA) which will get a back-up from the grid if PV cannot fill the load.

The orientation of PV in both locations is facing north, because both locations are located in the southern latitude. The orientation of the PV module follows the roof orientation obtained with the GPS Compass Navigator application.

Figure 6. Determine Roof / PV Orientation with GPS Compass Navigator

The slope of PV module (β) in both locations is the same because the latitude of the two locations tends to be the same, namely 8.66 south latitude and the slope of PV is determined by looking for the maximum sun height in degrees (α) using:

$$\begin{aligned}\alpha &= 90^\circ + \text{lat} - \delta \\ &= 90^\circ + 8.66^\circ - 23.45^\circ \\ &= 75.21^\circ\end{aligned}$$

While the angle that must be formed by the PV module against the earth's surface/the slope of PV (β), can be obtained as follows:

$$\begin{aligned}\beta &= 90^\circ - \alpha \\ &= 90^\circ - 75.21^\circ \\ &= 14.79^\circ = 15^\circ\end{aligned}$$

So, the optimal PV module slope is 15° , the slope of PV in both locations is not optimal, which is 20° obtained from the Angle Meter Pro application.

Figure 7. Determining Roof / PV Slope with Angle Meter Pro

C. Energy Simulation

Potential of PV rooftop energy production in both PLN buildings is simulated using the HOMER application. There are three scenarios in this simulation, the first without using a solar tracker with the slope angle of the PV module according to the installed PV. Second, simulating the installed PV with vertical axis continuous adjustment solar tracker where the axis of PV movement is in the north and south so that PV moves from east to west, selection of this single axis vertical type solar tracker because this type is the most commonly used type and produces more energy from other single axis types [9]. Third, Solar tracker two axis where PV moves freely from east to west and also north to south according to where the sun comes from. So that the rooftop PV simulation results in Building #1 and Building #2 on the HOMER can be seen as follows:

TABLE I. RESULT OF HOMER PV BUILDING #2 SIMULATION

Month	No Tracking (kWh)	Single Axis (kWh)	Two Axis (kWh)
Jan	1,090	1,436	1,527
Feb	1,058	1,308	1,363
Mar	1,328	1,569	1,682
Apr	1,381	1,534	1,686
May	1,474	1,577	1,823
Jun	1,357	1,423	1,670
Jul	1,367	1,445	1,667
Aug	1,453	1,589	1,813
Sep	1,458	1,699	1,894
Oct	1,461	1,791	1,962
Nov	1,217	1,589	1,757
Dec	1,153	1,530	1,652
Total (kWh)	15,799	18,491	20,497

Potential of PV energy production Building #2 for a year from HOMER simulation results is 15,799 kWh/year. PV energy potential with single axis solar tracking is 18,491 kWh/year which is 17.0% greater than the energy potential without solar tracker. PV energy potential with two axis solar tracking is 20,497 kWh/year which is 29.7% greater than energy potential without solar tracker.

TABLE II. RESULT OF HOMER PV BUILDING #1 SIMULATION

Month	No Tracking (kWh)	Single Axis (kWh)	Two Axis (kWh)
Jan	3,267	4,303	4,576
Feb	3,172	3,921	4,083
Mar	3,981	4,701	5,041
Apr	4,140	4,598	5,053
May	4,418	4,726	5,461
Jun	4,068	4,266	5,003
Jul	4,096	4,331	4,996
Aug	4,354	4,760	5,433
Sep	4,369	5,090	5,675
Oct	4,379	5,368	5,878
Nov	3,646	4,761	5,263
Dec	3,457	4,586	4,950
Total (kWh)	47,347	55,413	55,413

Potential of PV energy production Building #1 for a year from HOMER simulation results is 47,347 kWh/year. PV energy potential with single axis solar tracking is 55,413 kWh/year which is 17.0% greater than the energy potential without solar tracker. PV energy potential with two axis solar tracking is 55,413 kWh/year which is 29.7% greater than energy potential without solar tracker.

D. Actual Energy Production

PV rooftop energy production in Building # 2 is obtained from May 2017 to April 2018 with actual energy production data as follows:

TABLE III. ACTUAL ENERGY PRODUCTION PV BUILDING #2

Year	Month	Energy Production (kWh)
2017	May	1,519
	Jun	1,275
	Jul	1,297
	Aug	1,359
	Sep	1,458
	Oct	1,342
	Nov	994
	Dec	992
2018	Jan	1,002
	Feb	1,196
	Mar	1,353
	Apr	1,589
Total		15,375

The largest PV energy production is in April 2018 and the smallest PV energy production in December 2017, with an average energy production in one year is 1,281 kWh/month. The energy produced by PV supplies to office loads by 6% where the total building # 2 load in one year is 254,177.2 kWh with the energy produced by PV for one year is 15,375.4 kWh, the need for loads not yet supplied by PV will be supplied by the PLN grid.

PV rooftop energy production in Building # 1 obtained from June 2017 to May 2018 with actual energy production data as follows:

TABLE IV. ACTUAL ENERGY PRODUCTION PV BUILDING #1

Year	Month	Energy Production (kWh)
2017	Jun	796
	Jul	2,438
	Aug	3,984
	Sep	4,333
	Oct	2,968
	Nov	2,009
	Dec	1,381
2018	Jan	1,446
	Feb	1,481
	Mar	1,661
	Apr	2,010
	May	4,449
Total		28,955

The largest PV energy production is in May 2018 and the smallest PV energy production in June 2017, with an average annual energy production of 2,413 kWh / month. Energy produced by PV supplies 3% of office expenses for a year from June 2017 to May 2018 where the total load of Building # 1 in that year is 879,095.31 kWh with the energy produced by PV for the year is 28,955.31 kWh, the need for loads not yet supplied by PV will be supplied by the PLN grid.

E. Energy Production Analysis

Comparison of actual energy production with energy production simulation results or potential energy production in Building # 2 is indicated by the following diagram:

Figure 8. Diagram of Actual Energy Production and Potential Energy with HOMER Simulation

Comparison of Building #2 potential energy production / simulation results with Building # 2 energy production is 3%. A small difference in potential energy production with actual energy production in Building # 2 can occur because PV in Building # 2 there is no equipment damage that occurs in the 1 year, except that there is no maintenance and no module cleanliness attention. Energy production in April was greater than its potential because in April 2018 there was only 2 rainy days and no cloudy days so that in April 2018 PV had a long duration of sunlight. Energy production in November and December has a considerable difference from its energy potential, this is because in November and December 2017 there are many rainy days and cloudy days

so that the PV surface gets less sunlight. Below is a table of the number of rainy days and cloudy days below:

TABLE V. DENPASAR CITY WEATHER DATA

Year	Month	Rainy (days)	Cloudy (days)	Sunshine Duration (Hour)
2017	May	9	4	6.84
	Jun	11	6	6.48
	Jul	10	15	6.24
	Aug	2	8	7.2
	Sep	4	5	7.68
	Oct	15	4	7.68
	Nov	22	2	3.48
	Dec	22	4	3.96
2018	Jan	25	3	3.6
	Feb	20	2	6.36
	Mar	13	4	6.48
	Apr	2	0	8.16
	May	3	0	8.04

Figure 9. Diagram of PV Energy Production Building # 2 with Sunshine Duration

In the diagram above, a comparison of the actual PV rooftop energy production Building # 2 with sunshine duration in Denpasar City has the same graphical pattern which can be concluded that the PV rooftop energy production Building # 2 is directly equivalent to the duration of sunshine in Denpasar city at the same time.

Comparison of actual energy production with energy production simulation results or potential energy production in Building # 1 is indicated by the following diagram:

Figure 10. Diagram of Actual Energy Production and Potential Energy with HOMER Simulation

Energy Production PV Building #1 and Sunshine Duration at Denpasar

Figure 11. Diagram of PV Energy Production Building # 1 with Sunshine Duration

Energy production PV Building # 1 has a significant difference from its energy production with its energy potential which is 39%, this is because in October 2017 to April 2018 there was damage to one of the inverters that got a breakdown in that inverter's fuse, which caused a reduction in PV energy production of Building #1 from October 2017. In June and July 2017 the energy production of PV Building # 1 differs greatly from its potential because there are still component adjustments in the synchronization settings on inverters when paralleled, which is PV rooftop in the Office Building # 1 is installed since the end of May 2017. Building # 1 also does not carry out routine cleaning treatments.

TABLE VI. EFFECT OF PV SLOPE VARIATIONS ON ENERGY PRODUCTION IN BUILDING #2

PV Slope	Energy Simulation Building #2	The energy of each slope is divided by optimal energy	Notes
0°	15,823	0.9905	Horizontal
5°	15,941	0.9979	< Optimal
15°	15,974	1.0000	Optimal
20°	15,799	0.9890	Installed
25°	15,590	0.9760	> Optimal
30°	15,304	0.9581	> Optimal
45°	14,016	0.8774	> Optimal

TABLE VII. EFFECT OF PV SLOPE VARIATIONS ON ENERGY PRODUCTION IN BUILDING #1

PV Slope	Energy Simulation Building #1	The energy of each slope is divided by optimal energy	Notes
0°	47,421	0.9906	Horizontal
5°	47,774	0.9979	< Optimal
15°	47,873	1.0000	Optimal
20°	47,347	0.9890	Installed
25°	46,723	0.9760	> Optimal
30°	45,866	0.9581	> Optimal
45°	42,010	0.8775	> Optimal

From the table above we can see the effect of the slope angle of PV where energy production at the optimal PV slope is greater than the energy production at the installed PV slope angle, which is 175kWh for Building # 2 and 526kWh for Building # 1. The PV slope of the module Building # 1 and Building # 2 is not the same as the slope of the calculation because the installed PV slope follows the slope of the building roof which causes no optimal solar irradiation and reduced energy produced by PV. HOMER can simulate the effect of the PV angle that is not optimal for energy production as shown by the table above.

IV. CONCLUSION

The PV rooftop in Building # 1 and Building # 2 has a certified rooftop PV component and an optimal module orientation which is facing north, but the PV module slope that follows the roof slope angle is 20 ° where it is not the same as the optimal PV module slope calculation is 15 °. This not optimal slope of PV causes the PV surface to not get effective sunlight and affects the PV energy production. If the slope angle of PV is smaller or bigger than the optimal slope angle, then smaller energy can produced.

PV energy production in Building # 2 is not much different with its energy potential is 3%. PV energy production in Building # 1 is far different from its energy potential is 39%, this is due to damaged components, not optimal PV slope, module cleanliness and weather.

The factors that affect energy production in Building # 2 are the less optimal module angle so that it does not optimal to get sunlight, module cleanliness can also cause the module not optimal to get sunlight, and weather which are plenty of rainy days and cloudy days so that it does not optimal to get sunlight. The factors that affect energy production in

Building # 1 are damage to one of the inverters that got a breakdown in that inverter's fuse, there are still component adjustments in the synchronization settings on inverters when paralleled, the module's slope angle is less than optimal where the slope angle follows the slope angle the roof is 20 ° while the optimal angle is 15 ° so the module is less optimal in getting sunlight, the cleanliness of the module can cause obstruction of the module to get sunlight, and the weather where there are plenty of rainy days and cloudy days so that it lacks of sunlight.

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