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Grid Connected Rooftop PV Simulation for Office Building Under Indonesian Rooftop PV Scheme Using HOMER

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Abstract. The Indonesian government has issued the Minister of Energy and Mineral Resources (MEMR) Regulation 49/2018 regarding the utilization of rooftop solar power systems by customers of utility grid provider (PT Perusahaan Listrik Negara). The policy aims to encourage the penetration of renewable energy usage to reduce carbon gas emissions. This policy governs the general requirements and procedures for the installation of rooftop PV(photovoltaic) systems by utility grid customers. Therefore, economic analysis is needed to be known the impacts to the customers. This study will simulate the 4-storey office building which electricity supplied by grid connected 41 kWp of rooftop PV without battery storage under PV rooftop scheme using HOMER (Hybrid Optimization of Multiple Energy Resources) software. This case study simulate the new for Environmental Studies Center of Gadjah Mada University (PSLH UGM) building located in Yogyakarta, Indonesia. From this study will be obtained the value of the cost of energy (COE). In this simulation, the 41kWp rooftop PV supplies 485.32 kWh/day and 148.21 kW peak demand load. The cost of energy generated from on grid rooftop PV system is 1.431,00 IDR/kWh, while the grid rates is 1.468,00 IDR.

INTRODUCTION

The Indonesia Government is issuing policies as on its efforts to reduce the impact of global warming as a commitment on Paris Agreement to reduce greenhouse gases. Based on Indonesian National Energy Policy (Kebijakan Energi Nasional), the government target the renewable energy mix is 23% in 2025 and 31% in 2050. While the MEMR regulation 49/2018 set about the policy of rooftop PV. Rooftop PV policy contains some rules regarding restrictions and tariff scheme of the electrical energy generated from rooftop PV. The rooftop PV capacity connected to grid is limited to not exceed the customer installed grid capacity. The price of exported energy generated from rooftop PV is valued as 65% of grid energy sold to customer price[1]. Customers also couldn't get direct incentives of money from grid provider in case of excess energy generated, but it will be an incentive rebates for next month grid electricity bill. The incentive balance will be set to zero in case in the next three month the exported energy accumulated is higher than the imported energy from the grid. From the regulation, its necessary to be known the economic value of PV application. This paper will analyze the cost of energy (COE) of on grid office building (study case: new PSLH building) rooftop PV system application using (MEMR) Regulation 49/2018 scheme. The COE of PV system will be compared with utility rates so it will be known the economic value of PV application.

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METHODOLOGY

The study will be model the PV rooftop that installed on the office building using HOMER energy modelling software under PV rooftop regulation and scheme. Results from simulation of HOMER software is COE, which could be compared as an economic value.

HOMER Software

HOMER (Hybrid Optimization of Multiple Energy Resources) is a software that used to simulate the microgrid energy system. For solar energy modelling, the equation to calculate the output of the PV array[2]:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\overline{G}_T}{\overline{G}_{T,STC}}\right) \left[1 + \alpha_P \left(T_C - T_{C,STC}\right)\right] \quad (1)$$

Y_{PV} = the rated capacity of the PV array, meaning its power output under standard test conditions [kW]
f_{PV} = the PV derating factor [%]
$\overline{G}_T$ = the solar radiation incident on the PV array in the current time step [kW/m^2]
$\overline{G}_{T,STC}$ = the incident radiation at standard test conditions[1 kW/m^2]
αP = the temperature coefficient of power [%/°C]
T_C = the PV cell temperature in the current time step [°C]
$T_{C,STC}$ = the PV cell temperature under standard test conditions [25°C].

HOMER defines the levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system. The COE calculated by HOMER using the following equation[3]:

$$COE = \frac{C_{ann,tot} - c_{boiler} H_{served}}{E_{served}} \quad (2)$$

$C_{ann,tot}$ = total annualized cost of the system [$/yr]
c_{boiler} = boiler marginal cost [$/kWh]
H_{served} = total thermal load served [kWh/yr]. In systems, such as wind or PV, that do not serve a thermal load ($H_{thermal}$=0)
E_{served} = total electrical load served [kWh/yr].

Building Model

The building model is the new PSLH UGM building that still under construction phase. The building is located in Yogyakarta (110^o 22' 37.2" S , 7^o 46' 30" E), Indonesia. It means the building located on equatorial regions and the southern hemisphere. The building located in East-West direction and slightly tilted so that the solar panel faced to the north at 14.29^o of azimuth angle. The geometrical structure gotten from DED (Detail of Engineering Design) document of the building. The illustration of rooftop PV layout on the building can be seen on Fig.1.

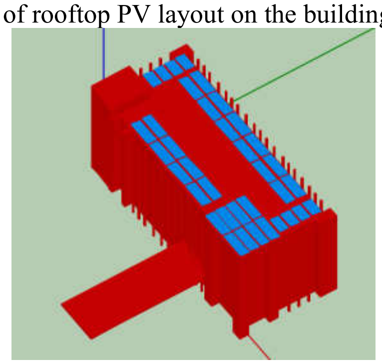

FIGURE 1. PV Layout

The Data Source

Data inputted to HOMER simulation software is based on following source:

- Load profile data obtained from the load profile of the previous PSLH building as a references
- To the solar Potential data obtained from NASA data that could be found in HOMER software
- Cost data obtained from the survey of Indonesia PV market prices.

Load Profile

HOMER need load profile data as the energy load of the building. The new PSLH building is still under planning phase, so the previous PSLH building load data is used as a references of the new PSLH building. The load profile curve usually divided at low demand and high demand. The building is used as an office building, so the load curve is divided into weekday load and weekend load. HOMER can interpolate the building load demand by scaling the daily load demand from load profile reference. The reference of daily load profile of previous PSLH building can be seen in Fig.2.

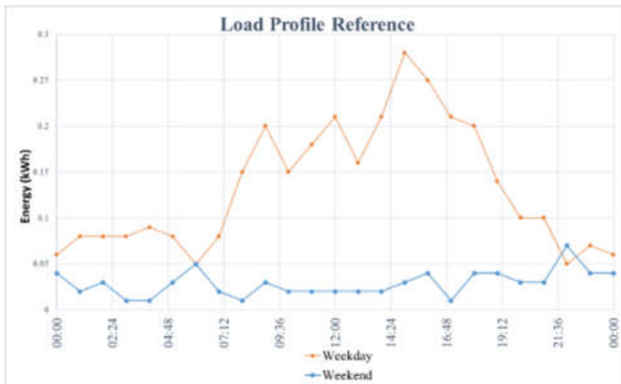

FIGURE 2. Previous PSLH building load profile as model references

The building has 109 kVA of peak load and supplied 130.9 kVA from the grid according to the building DED document. The scaled building energy intensity is 60 kWh/m^2/year from the HOMER result. The daily energy consumption calculated by multiplying energy intensity by area of the building and divided by 365, so the daily energy demand is (60 kWh/m^2/year × 2934.29 m^2)/365 days = 485.32 kWh/day.

PV Capacity dan Inverters

Rooftop PV capacity is only 41kWp, as the rooftop area limit that could be installed. PLTS system consists of 164 solar module with 250Wp of each solar modules. The inverters used in the system are 7 x 5000W inverter and 2 x 3000W inverter. Sunny Tripower 5000TL (5kW) and Sunny Boy 3000TL (3 kW) are used. Sunny Tripower is three-phase output inverter 5000TL, while the Sunny Boy 3000TL is one-phase output inverter. Efficiency of the Sunny Tripower inverters are quite high, more than 97%.

In the cost model, the price of solar module and inverter modules are used accordance to Indonesian PV market prices. For the transport, cables, mounting, installation and other costs are refers to the other PV project cost[4]. The cost of the operation and maintenance of PV is modelled by 1% of Capital Cost [5]. The detail cost of this rooftop PV can be seen on Table 1.

TABLE 1. Rooftop PV cost

	Details	Capital Cost	Operational dan Maintenance Cost	replacement	Life-time
PV Solar Module	164 x 250 Wp solar module Sunny-250Wp Monocrystalline	455.920.000,00 IDR	4.559.200,00 IDR	455.920.000,00 IDR /20 years	20 years
Inverter	7 x 5kW Sunny Tripower 5000tl 2 x 3kW Sunny Boy 3000TL	461.488.000,00 IDR	4.614.880,00 IDR	461.488.000,00 IDR /10 years	10 years
others	Modul mounting, cable, Dc combiner, frames, connector installation, etc	415.127.913,00 IDR	4.151.279,00 IDR	-	-
	Total cost	1.332.535.913,00 IDR	13.325.359,0 IDR	-	-

PV Tilt

Setting the tilt of solar modules is needed to get optimal PV energy generation results. The PV mounting type used in this system is fixed. It means that module mounted to cannot be moved follows the direction of the Sun. The advantages of PV that installed near the equator area, the sunlight is available year-round. As in general rules for PV, the solar module that are located in the southern hemisphere should be facing to the North, and vice versa. The tilt of solar modules can be calculated by its latitude. Optimum solar modules tilt calculated by simplified calculation [6]:

If the latitude is below 25°, use the latitude times 0.87 (3)

Because of the PV located on 110º 22' 37.2" S(Degree Minutes Seconds) or 7.775 S(Decimal), so the optimum tilt of solar modules are 7.775 × 0.87 = 6.76425°. the PV tilt illustration can be seen on Fig.3.

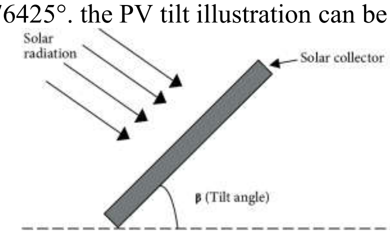

FIGURE 3. PV Tilt[7]

Minimum Row Spacing of PV Modules

To get optimal irradiance on solar modules in order not to experience the self shading of the PV modules, it is needed to consider the distance between the row/line module as shown in Fig.4.

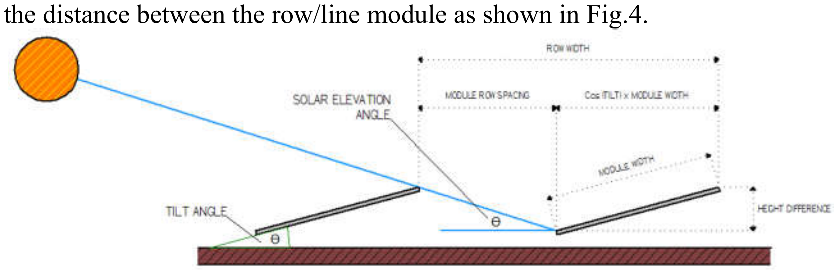

FIGURE 4. Module row spacing illustration

The distance between PV module can be calculated by height difference and length of PV modules. The height difference can be calculated using this equation[8]:

$$\text{Height Difference} = \text{Sin (Tilt Angle)} \times \text{Module Width}$$

In this case, the module length is 1.7 m so,

$$\text{Height Difference} = \text{Sin}(6.765) \times 1.7 \text{ m}$$
$$\text{Height Difference} = 0.2 \text{ m}$$

Using the height of PV module, it can be defined the shade length of PV module by the position of the Sun. Position of the Sun could be identified using the solar path data gotten from PVSyst Software by defining the latitude and longitude of Building location. The Sun path of the building can be seen in Fig.5.

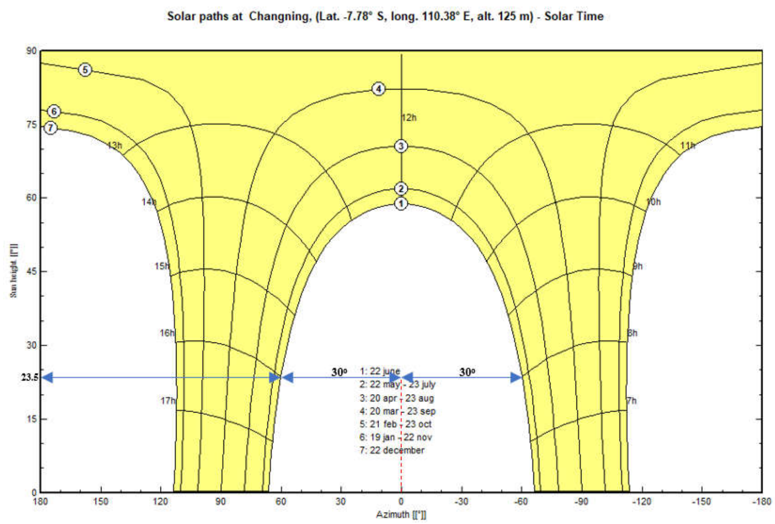

FIGURE 5. Solar path of the new PSLH building[9]

This simulation, picked a 8 AM to 4 PM as the optimum PV solar irradiance started and ended. Higher of Sun height affecting higher the irradiation occurred to PV solar modules. For the worse situation, the Sun height is 23.5^{o} on 22 June. Using trigonometry equation, it could be calculated the shade of PV modules come off. Shade of PV could be defined as module row spacing. Formula for module row spacing can be seen below:

$$\text{Module Row Spacing} = \text{Height Difference} / \text{Tan}(23.5)$$
$$\text{Module Row Spacing} = 0.2 \text{ m} / \text{Tan}(23.5)$$
$$\text{Module Row Spacing} = 0.46 \text{ m}$$

The inter-row spacing between the trailing edge of the first row of modules and the leading edge of the next row needs to be 0.4606 m. It also needed to consider the Azimuth angle and use it to figure the minimum module row spacing. The difference between North going in either direction turns out to be 30^{o} as shown in Solar path. Using trigonometry formula, it can be determined the Minimum Module Row Spacing bellow:

$$\text{Minimum Module Row Spacing} = \text{Module Row Spacing x Cos (Azimuth Correction Angle)}$$
$$\text{Minimum Module Row Spacing} = 0.4606 \text{ m x Cos}(30)$$
$$\text{Minimum Module Row Spacing} = 0.4 \text{ m.}$$

SIMULATION RESULT

On grid PV system is simulated in the HOMER that can be seen in Fig. 6. The daily average load of the building is 485.32 kWh/day with 148.21 kW of peak load supplied by Grid and PV. On grid PV system schematic on HOMER can be seen in Fig.6.

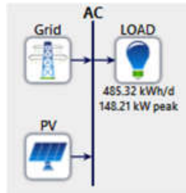

FIGURE 6. On grid rooftop PV schematic on HOMER software

In HOMER rooftop PV simulation, electric production values calculated according to PV rooftop tariff policy. The purchase price for electricity from the grid is 1.468,00 IDR/kWh and the selling price of the excess electricity production of PLTS is 954,20 IDR/kWh (65% × 1.468,00 IDR/kWh). Simulated on grid rooftop PV project lasted for 25 years. Economic parameters are set as 5% of inflation and 6% of discount rate. Other technical parameters are inputted on HOMER based on DED document.

The result is rooftop PV produce 59,593 kWh/year and the building is still consume 131,979 kWh/year from the grid. Amount of excess energy that produce from rooftop PV is of 14,431 kWh/year exported to the grid. In another words, rooftop PV contribute 31.1% of renewable energy source for the building. The rooftop PV energy exported to the grid usually occurs on the weekend, when the needs of the load is not too high. Therefore, the energy generated from rooftop PV on the weekdays is not enough to fully supply the demand load. Daily rooftop PV generation and demand load curve can be seen in Fig.7.

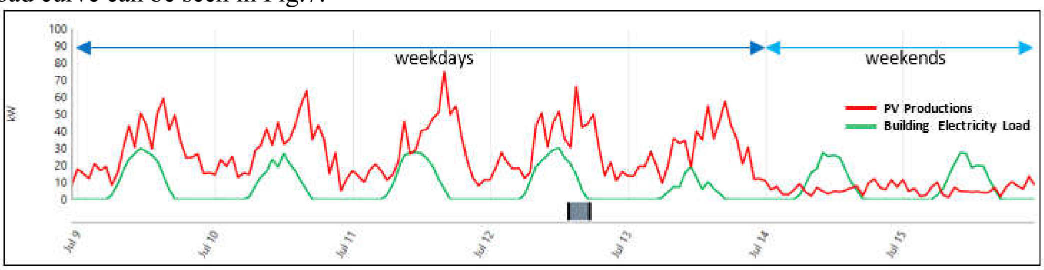

FIGURE 7. Daily rooftop PV energy and building load

With 1.33 billion IDR of the capital cost and 214 million IDR/year of operating and maintenance costs of on grid rooftop PV of the building, it can supply the building electricity load with 1.431,00 IDR/kWh of cost of energy. Meanwhile, the grid rates is 1.468,00 IDR as cost of energy in grid only system.

CONCLUSION

Limited area of the building rooftop affecting the rooftop PV capacity that could be installed. Rooftop PV capacity of the building can't be maximized to the maximum regulation allowance. Exported PV energy priced only 65% from grid price, so it's good to directly supply the building load from generated PV energy. Applying rooftop PV is suitable to supply the office building. The office building has peak load on the day as same as the PV generation occurred. In this simulation, the 41kWp rooftop PV supplies 485.32 kWh/day and 148.21 kW peak demand load. The export energy from rooftop PV to the grid occurred during the weekend only. In the case study, cost of energy generated from on grid rooftop PV system is 1.431,00 IDR/kWh, while the grid rates 1.468,00 IDR.

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