Technical Analysis on Household-Scale Rooftop Solar Power Plant Design with On-Grid System in Semarang City

Jaka Windarta[1,2*], *Singgih Saptadi*[3], *Denis*[2], *Dimas Adi Satrio*[2], *Johanes Soritua Silaen*[2]

[1]School of Postgraduate Studies, Diponegoro University, Semarang-Indonesia
[2]Department of Electrical Engineering, Faculty of Engineering, Diponegoro University, Semarang-Indonesia
[3]Department of Industrial Engineering, Faculty of Engineering, Diponegoro University, Semarang-Indonesia

Abstract. Indonesia has 442 GW total of potential renewable energy equivalence which can be used for electricity generation. However, the energy utilization in 2018 is only 8.8 GW or 0.019% of total potential renewable energy, while the biggest renewable energy potential is at 207.8 GWp. By also considering the growing number of household customers, utilizing the rooftop as the base of solar power plant generators can be an effective and efficient solution. The purposes of this research are to technically design and analyze the household-scale rooftop solar power plant potential with an on-grid system. Through the utilization of PVSyst 6.43 software and a variety of main components, this household-scale rooftop solar power plant potential performance planning is expected to generate 4.23 kWh / kWp per day.

Keywords: Solar power plant; On-grid; Technical and Economic Analysis; PVSyst 6.43

1 Introduction

The demand for electricity has always grown from time to time compared to other energies. The electricity demand is projected to meet 2.214 TWh in 2050, or it can be said that the demand will increase for about 9 times from the electricity demand in 2018 in the amount of 254,6 TWh. The growth rate of electricity demand may reach an annual average score of 7% over the 2018-2050. The electricity demand during the projection period is relatively common with the largest portion of the household sector, industrial sector, commercial sector, transportation sector, and other sectors. The share of household electricity sector will increase from 49% in 2018 to 58% in 2050. This condition is primarily affected by the household growth number which may increase from 67 million in 2018 to approximately 80 million in 2050 [1]. To meet the electricity demand which has increased 9 times from 2018,

* Corresponding author: jakawindarta@lecturer.undip.ac.id

in 2050, the electricity production will reach 2.562 TWh. The decrease in fossil energy production especially petroleum and global commitments in reducing greenhouse and gas emission has driven the Indonesian government to intensify important and sustainable roles in new and renewable energy as part of maintaining energy autonomy and endurance. In accordance with PP regulation number 79 of 2014 concerning the National Energy Policy, the targetted new and renewable energy combination in 2025 is at least 23% and in 2050 is at least 31%. Indonesia has big potency on new and renewable energy which will be achievable and meet the primary target [1]. Indonesia has a total renewable energy potential equivalent to 442 GW which can be used for electricity generation, whereas the utilization is only 8.8 GW or it is only 0.019% of the total renewable energy in 2018. The biggest potential for renewable energy may come from solar energy at 207.8 GWp. To accelerate New and Renewable energy development, the government has established several regulations such as *Peraturan Presiden No. 4* in 2016 (Article 14) concerning the Electricity Infrastructure Acceleration prioritizing the use of new and renewable energy [2], *Peraturan Menteri ESDM No. 50* in 2017 concerning the Utilization of Renewable Energy Sources as the Supply of Electricity [3], and *Peraturan Menteri ESDM No. 49* in 2018 concerning the Use of Rooftop Solar Power Generation System by state-owned corporation *Perusahaan Listrik Negara* (PLN) customers [4]. With the high potential of solar energy in Indonesia and the indorsement from government regulations, this system is expected to be a solution to comply with the high electricity demand in the future by utilizing the solar cell as the source of electrical energy. Solar Power Plant or *Pembangkit Listrik Tenaga Surya* (PLTS) is one of the examples of the renewable energy application by taking advantage of the sun as the primary energy source. By considering the growing number of household customers, utilizing the rooftop's consumers as solar power generator base can be an effective and efficient solution. Therefore, the purpose of this research is to analyze technical feasibility of rooftop solar power plant system with a household-scale on-grid system by the PVSyst 6.43 software utilization.

2 Theoretical Background

2.1 Solar Radiation

Solar radiation is defined as the amount of energy received per unit area and time on earth. The value can be determined depending on such factors, for instance, the location latitude, the season and weather, and the timing [5]. There are two types of radiation which are direct radiation generated from the sun, and indirect radiation generated from atmospheric particles scattering. Indonesia is geographically located on the equator in exact and this resulting in such advantages and great potential of solar energy utilization [6]. Indonesia has a relatively high radiation level which is equal to 4.80 kWh/m2/day [7].

2.2 Solar Power Plants

Solar Power Plant is a sunlight-based power plant that uses solar cells to convert the photon sunray radiation into electricity. Solar cells are made from sheer layers of pure silicon and such semiconductor materials [8]. Solar Power Plants is friendly to the environment and it does not produce any noise nor harmful waste to the surroundings. There are several factors that influence the solar cell output power efficiency such as solar radiation, solar cell temperature, solar panel orientation, and shadow leverages [9].

2.3 Technical Analysis

The technical analysis is conducted based on the rooftop solar power plant capacity, major components specification utilization and determination, solar panel orientation, and the generated power from the plant. The power generated by rooftop solar power plant is affected by some factors including sunray radiation in the research area, the solar panel slope and its direction, sunlight, temperature, and the technical performance. This technical performance is predicted to decrease in time because of the solar module degradation. The quality of rooftop solar power plant can also be seen by its performance ratio. In general, performance ratio is shown in percentage value that shows the total power produced by the system and also the losses compared while the system is working in STC condition. Solar power plant losses are due to solar panel efficiency, temperature, and inverter efficiency [10].

3 Simulation, Result, and Analysis

3.1 Simulation

To stimulate the solar power plant prototype design on PVSyst 6.43, such data are required, for instance, the factors that affect PVSyst 6.43 software simulation result. The factors are including the solar power plant geographic location, solar energy potential data, the temperature, the radiation spread, wind speed, solar panel orientation in the spot, specifications of the components used, and the daily load estimation. After the simulation process is conducted, the amount of potential electrical energy will be shown by the rooftop solar power plant in the research area. There are numerous values that indicate the amount of produced electrical power, the amount of electricity delivered to the load, and the amount of electric power supplied to the grid. In addition, the solar power plant loss diagram and performance will be shown in graphical data. In this research, a household-scale rooftop solar power plant is designed in Sambiroto Asri Cluster residence number A9 in Semarang City, Indonesia.

Fig. 1. Research Location in Sambiroto Asri Cluster residence number A9, Semarang City

The research area is located astronomically in 7°1'56.06" South Latitude and 110°27'28.58" East Longitude. According to NASA Prediction of Worldwide Energy Resources data [11], sun insolation in 2019 in this area is 5,59 kWh/m2/day. Moreover, data generated from NASA Prediction of Worldwide Energy Resources shows the diffuse radiation and wind velocity, also Semarang city temperature data is generated from Semarang-based Station Meteorology, Climatology, and Geophysical Agency. The data mentioned above can be used to generate the result of potential solar energy usage into a rooftop solar power plant in the research area.

Table 1. Insolation, Temperature, Diffuse Radiation, and Wind Velocity in Semarang City.

Month	Insolation ($kWh/m^2.day$)	Temperature (°C)	Diffuse Radiation ($kWh/m^2.day$)	Wind Velocity (m/s)
January	4,60	27,6	2,33	2,59
February	5,29	27,9	2,39	1,42
March	4,55	27,6	2,32	2,06
April	5,08	28,7	2,06	1,76
May	5,41	29,0	1,76	2,65
June	5,14	28,3	1,62	2,82
July	5,37	27,7	1,63	3,04
August	5,94	28,0	1,80	3,11
September	6,49	28,8	2,06	2,99
October	6,54	29,8	2,31	2,75
November	6,02	30,1	2,34	2,37
December	5,30	28,7	2,32	1,42

According to the real condition in the research area, the planning of the Rooftop Solar Power Plant utilizes a fixed tilted plane with such adjustment to the rooftop condition for about 30° and azimuth 80°.

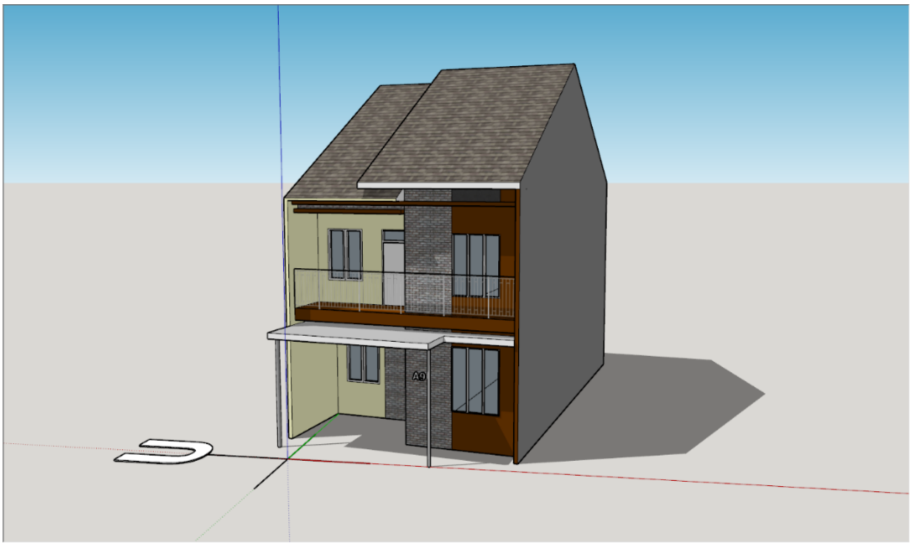

Fig. 2. Visualization in the Research Area Located in Sambiroto Asri Cluster Residence, Semarang city.

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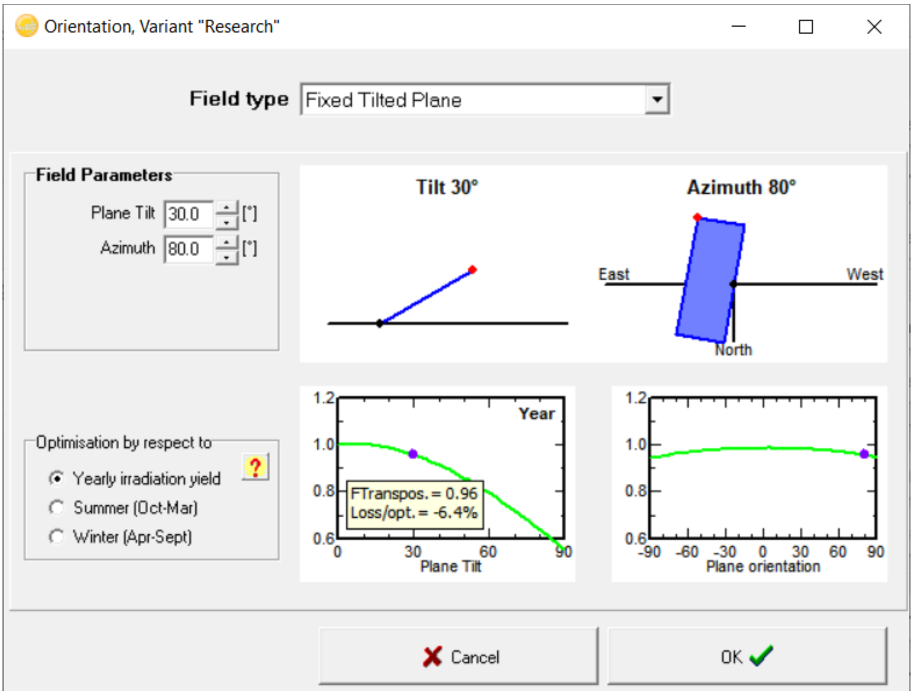

Fig. 3. Solar Module orientation

The major components are solar panels and inverters. Each component consists of two alternative options. Solar Panel alternative option is polycrystalline or monocrystalline solar panel with 405 Wp capacity, while the inverter alternative option chosen for this research is an inverter with more than 97% efficiency. The alternative component options used for Solar Power Plant will be assigned into PVSyst 6.43 software and it will be stimulated in the Rooftop Solar Power Plant planning as explained below.

Table 2. Solar Panel Specification Variation 1 (Canadian Solar CS3W405P)

Specification	Value
Maximum Power (Pmax)	405 Wp
Open Network Voltage (Voc)	47,4 V
Short Circuit Current (Isc)	10,98 A
Maximum Voltage (Vmp)	38,9 V
Maximum Current (Imp)	10,42 A
Efficiency Module	18,3 %
Dimension (mm x mm x mm)	2108 x 1048 x 40
Price	Rp 3.900.000

Table 3. Solar Panel Specification Variaton 2 (Trina Solar TSM-405DE15M(II))

Specification	Value
Maximum Power (Pmax)	405 Wp
Open Network Voltage (Voc)	49,2 V
Short Circuit Current (Isc)	10,92 A
Maximum Voltage (Vmp)	40,5 V
Maximum Current (Imp)	10 A
Efficiency Module	19,9
Dimension (mm x mm x mm)	2024 x 1004 x 35
Price	Rp 4.000.000

Table 4. Inverter Specification Variation 1 (Solax X1-1.1-S)

Specification	Value
Input DC	
Maximum Solar Array Power	1250 W
Maximum DC Voltage	400 V
Maximum Input Current	12 A
MPPT Voltage Range	55-380 V
Output AC	
Maximum Output Power	1100 W
Grid Voltage Range	180-280 V
Maximum Output Current	5,5 A
General Data	
Maximum Efficiency	97,1 %
Dimension	267 x 328 x 116 mm
Price	Rp 6.000.000

Table 5. Inverter Specification Variation 2 (Solis 1000W)

Specification	Value
Input DC	
Maxiumum Solar Array Power	1200 W
Maximum DC Voltage	600 V
Maximum Input Current	11 A
MPPT Voltage Range	50-500 V
Output AC	
Maximum Output Power	1100 W
Grid Voltage Range	160-285 V
Maximum Output Current	5,2 A
General Data	
Maximum Efficiency	97,2 %
Dimension	310 x 373 x 160 mm
Price	Rp 5.500.000

According to component alternatives above, Rooftop Solar Power Plant that will be stimulated have four different configurations as shown in Table 6 below.

Table 6. Alternative Component Configuration of Rooftop Solar Power Plant

Variation	Solar Panel	Inverter	Array Configuration
1	Canadian Solar Polycrystalline 405 Wp Voc (47,4 V) Isc (10,98 A)	Solax X1-1.1-S Max Vin (400 V) Max Iin (12 A)	3 series of installed modules Voc (142,2 V) Isc (10,98 A)
2	Canadian Solar Polycrystalline 405 Wp Voc (47,4 V) Isc (10,98 A)	Solis Mini-1000-4G Max Vin (600 V) Max Iin (11 A)	3 series of installed modules. Voc (142,2 V) Isc (10,98 A)
3	Trina Solar Polycrystalline 405 Wp Voc (49,2 V) Isc (10,52 A)	Solax X1-1.1-S Max Vin (400 V) Max Iin (12 A)	3 series of installed modules. Voc (147,6 V) Isc (10,52)
4	Trina Solar Polycrystalline 405 Wp Voc (49,2 V) Isc (10,52 A)	Solis Mini-1000-4G Max Vin (600 V) Max Iin (11 A)	3 series of installed modules. Voc (147,6 V) Isc (10,52)

Estimated daily load data in the research area is generated manually and periodically to obtain an exact daily load profile data. The research area has an installed electrical capacity of 1300VA. The following table will display the daily load profile in the researh area.

Table 7. Daily Load Profile in the research area

Load	Amount	Power (W)	Time Length (h)	Energy (Wh)
Lamp	10	10	12	1200
TV	1	50	7	350
AC	1	320	13	4160
Refrigerator	1	100	24	2400
Washing Machine	1	300	2	600
Laptop	1	135	12	1260
Handphone	1	5	12	60

According to the Table 7, the daily load profile in the research area will be modified into hourly load profile as follows.

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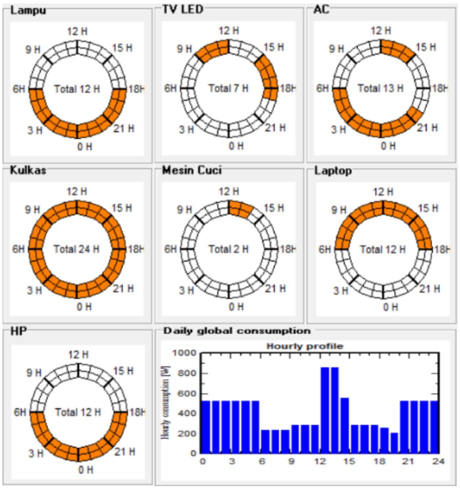

Fig. 4. Daily Load profile distribution in the research area.

The simulation utilizing PVSyst 6.43 software can be conducted after determining and inputting all data.

3.2 Result

The result of PVSyst 6.43 simulation on household-scale rooftop solar power plant planning variations 1, 2, 3, and 4 can be seen in the figures below.

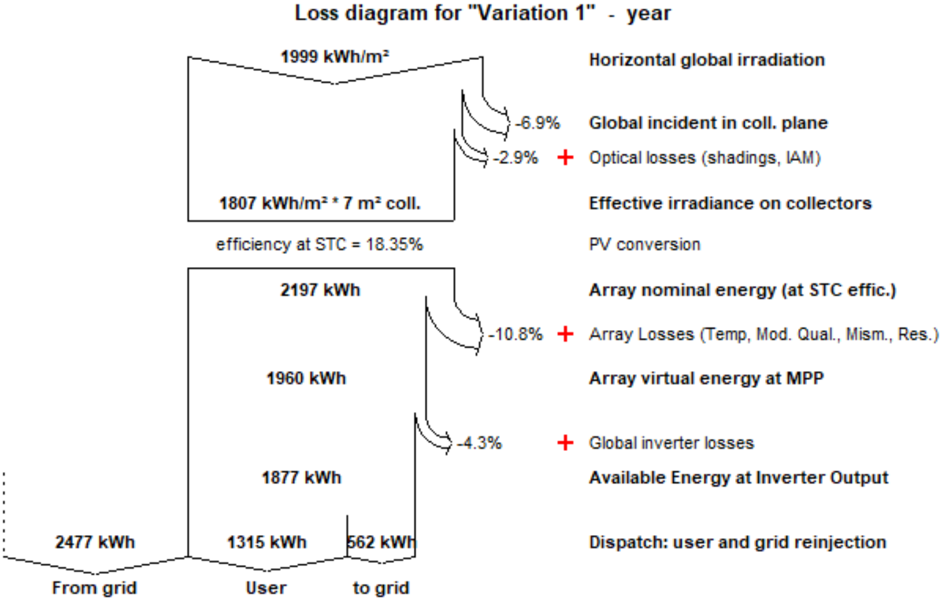

Fig. 5. Variation 1 Results

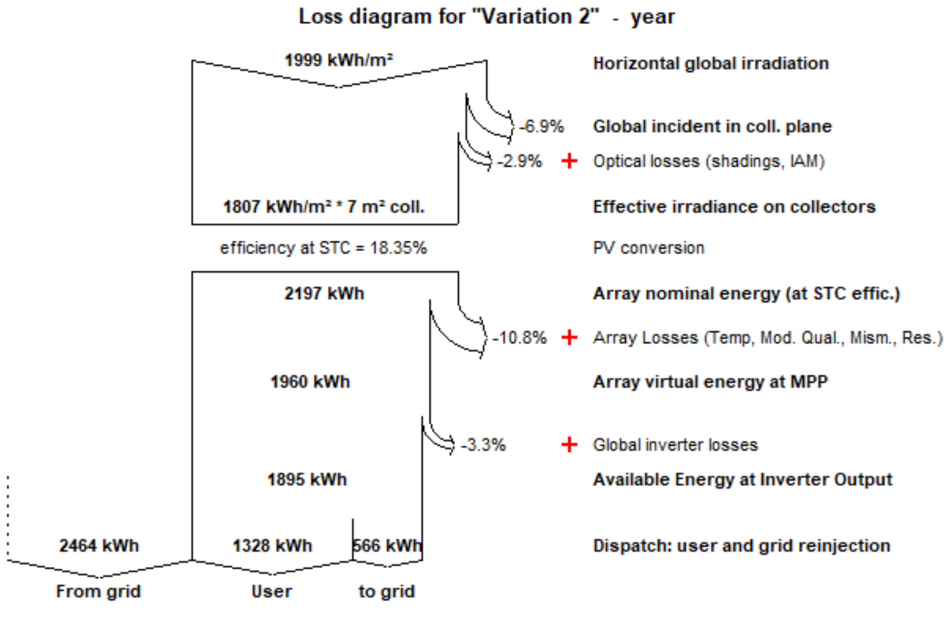

Fig. 6. Variation 2 Results

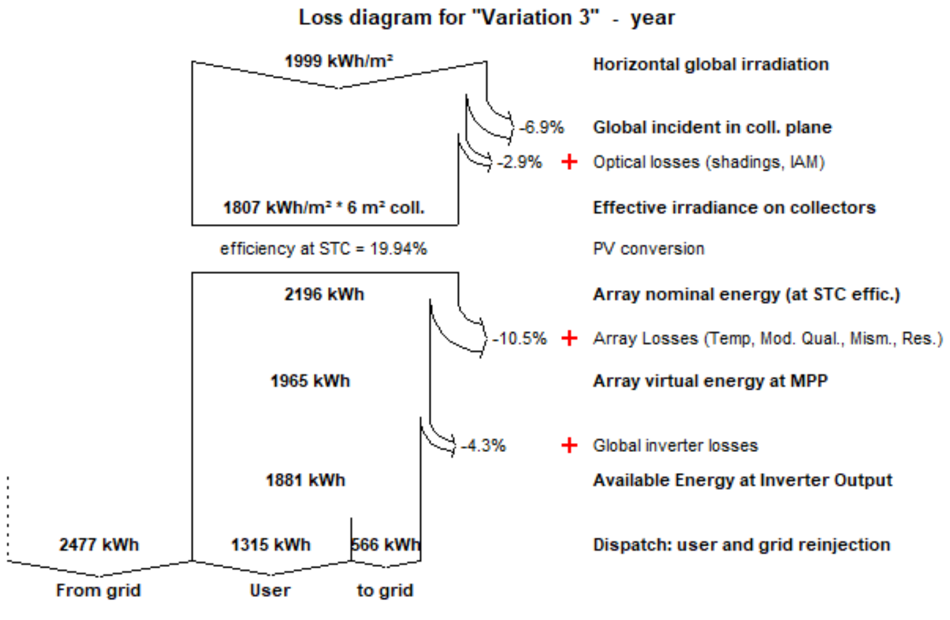

Fig. 7. Variation 3 Results

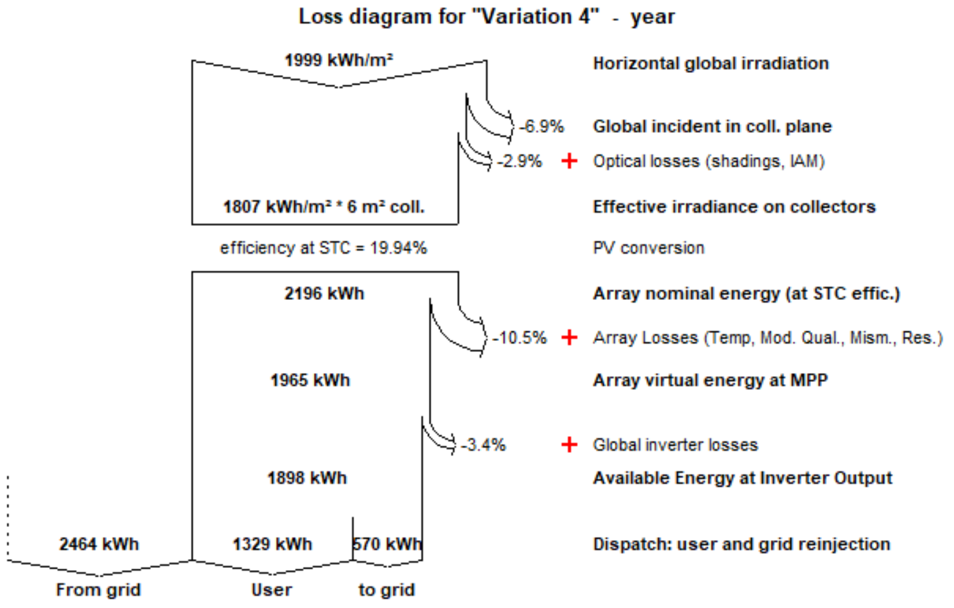

Fig. 8. Variation 4 Results

3.3 Analysis

Based on the simulation results of PVSyst 6.43 software household-scale rooftop solar power plant in the research area, Table 8 is aimed to calculate each variations as follows.

Table 8. The result of PVSyst 6.43 simulation in Rooftop Solar Power Plant Variation 1, 2, 3, and 4.

Variation	Solar Panel Insulation (kWh/m²)	STC Array Electric Energy (kWh)	Array Output Electric Energy (kWh)	Inverter Output Electric Energy (kWh)	Performance Ratio (%)
Variation 1	1861,3	2197	1960	1877	83
Variation 2	1861,3	2197	1960	1894	83,8
Variation 3	1861,3	2196	1965	1881	83,2
Variation 4	1861,3	2196	1965	1898	83,9

It can be concluded from Table 8 that the production sunray array electric energy production in variation 1 and 2 have bigger value in the amount of 2197 KWh per year rather than the variation 3 and 4 which only equal to 2196 KWh per year. Thus, it has 1 KWh deviation caused by the solar panel efficiency and surface area used in this research. The variation 1 and 2 utilize Canadian Solar Panel type CS3W405P with an efficiency value of 18.3% and it has surface area of 6,63 m^2 which produces electrical energy output array of 2197 KWh during STC condition. On the other hand, the variation 3 and 4 utilize Trina Solar Panel type TSM-405DE15M(II) with an efficiency value of 19,9% and it has surface area of 6,09 m^2 which produces electrical energy output array of 2196 KWh. Therefore, it can be concluded that the greater solar panel efficiency and the larger solar panel surface area will be resulting in better results. The efficiency is also depending on the type of solar panel. Monocrystalline solar panel types generally have better efficiency because the primary material for making panel which is silicone has greater concentration rather than the polycrystalline type [12]. However, at the same power position, monocrystalline types have smaller panel surface area than the polycrystalline types.

The annual array output for electrical energy in variation 1 and 2 suffered losses from STC conditions of 237 kWh or 10.79% from the STC condition so it becomes 1960 kWh. Moroever, the annual array output for electrical energy in variation 3 and 4 suffered losses from STC conditions of 231 kWh or 10,52% from the STC condition so it results of 1965 kWh. It can be said that these solar panel types have similar losses characteristics for about 0.27% adrift.

If variation 1 and 2 is compared by also looking at the same sunray array, the output electric energy in variation 2 is larger than variation 1. This due to the usage of Solis inverter MINI-1000-4G type which has efficiency rate of 97.2% in variation 2 is bigger than the usage of Solax inverter X1-1.1-S type which has efficiency rate of 97.1%.

This also can be seen in variation 3 and 4. The output electric energy in variation 4 is larger than variation 2. This due to the usage of Solis inverter MINI-1000-4G type which has efficiency rate of 97.2% in variation 2 is bigger than the usage of Solax inverter X1-1.1-S type which has efficiency rate of 97.1%. Hence, it could be said that the inverter with a bigger efficiency produces a bigger electrical output as well.

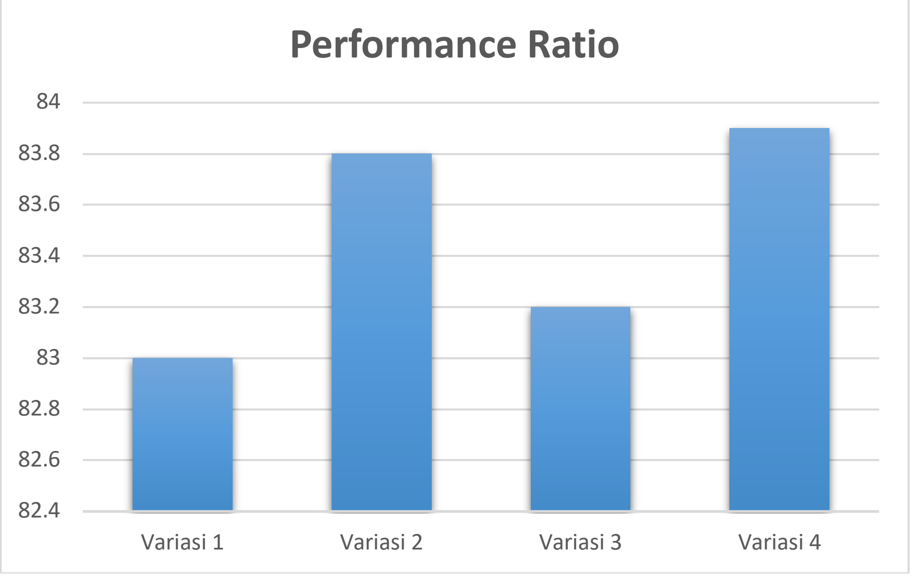

Fig. 9. Performance Ratio of household-scale rooftop solar power plant in research area.

It can be concluded that the variation with the biggest performance ratio is variation 4 which has an 83.9% ratio, and the smallest performance ratio is variation 1 which has an 83% ratio.

4 Conclusion

The solar power plant system designed in this research is connected to the grid (on-grid system). The rooftop solar power plant planning has four different variations which utilizes 3 solar panels with a capacity of 405 Wp and a 1000 W inverter. The electricity produced from this household-scale rooftop solar power plant in the research area is ranging from 1877-1898 kWh with a performance ratio ranging from 83-83.9%. Based on the performance ratio result, the most feasible variation is variation 4 with an 83.9% performance ratio value.

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