Design and implementation of 232.2 KWp rooftop on grid solar power plant

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Abstract. The need for large amounts of electrical energy and the negative impact of carbon emissions have encouraged all countries to develop renewable energy sources and reduce fossil energy sources which produce a lot of carbon emissions. One promising source of renewable energy is solar energy, which can be converted into electricity through Solar Power Plants. The Indonesian government has committed to increasing the renewable energy mix by 57% by 2035 and reducing carbon emissions by 29 % by 2030. To support the Indonesian government's commitment, the Widya Mandala Foundation has built Solar Power Plants on all campuses of Widya Mandala Surabaya Catholic University. This article intends to communicate the design and implementation of a 232.2 KWp rooftop and on grid Solar Power Plant located on one of these campuses. The Solar Power Plant has been designed and implemented using 430 units of 540 Wp solar panels, 2 units of 110 KWac inverters. It would produce 363.5 MWh of electricity per year. Based on the implementation results, the following output was obtained: from May to December 2022, was generated 221.788 MWh of electricity and 88.7 ton of CO2 avoided. Then from January 2023 to May 2023, was produced 145,400 MWh of electricity and 58.2 ton of CO2 was avoided. The implementation of 232,2 KWp Solar Power Plant is a significant step toward environmentally friendly energy. It also contributes to carbon footprint reduction and support sustainable development goal.

1 Introduction

Electrical energy is a vital basic need and contribute greatly to meeting human needs in this era of globalization. Without the fulfillment of electrical energy, of course, it will hamper human activities along with the current development of information technology. Research and development as well as the use of new and renewable energy are currently a strategic issue, especially in breaking down the dwindling use of fossil energy, the carbon emission footprint and the long-term environmental impacts [1]. The rate at which solar energy falls to the earth's surface is 120 petawatts, this means that this amount of energy in one day can

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meet the energy needs of the whole world for more than 20 years. This is of course a very large resource and energy potential to be developed [2]. Some of the obstacles encountered in the field include network flexibility, limited technology development, incomplete and clear pricing schemes [3]. Today the world is faced with the problem of increasing demand for electrical energy and the negative impact of carbon emissions from fossil fuel power plants. Research and development in the field of solar power plant as well as its techno-economic analysis have also been carried out in various agencies, local governments and various countries [4–7]. To overcome this problem, countries in the world have issued policies related to the use of renewable energy or environmental policies. For example, the state of Indonesia and the state of the Vatican.

Indonesia follows international energy policies, namely reducing greenhouse gas emissions, transforming towards new renewable energy, and accelerating the economy based on green technology. The National Energy Council has drawn up a roadmap for the energy transition towards net zero emission in 2060. Every year the new renewable energy target will increase, starting from 2025 with a target of 23 percent to 2060 with a target of 66 percent. Meanwhile the the second encyclical of Pope Francis, *Laodato Si*, was released which deplores environmental damage and global warming, and invites all people around the world to take "integrated and immediate global action" [8].

1.1 Utilization of solar energy

One promising source of renewable energy is solar energy, which can be converted into electricity through solar power plants. Electricity from solar energy is friendly to the environment because it does not produce CO2 emissions.

The potential for solar energy in the world is enormous. In Indonesia, the potential for solar energy is around 4.8 KWh/m2 or equivalent of 207.8 GWp, and only around 148 MWp has been utilized [1].

Based on the technology, there are three main types of solar power plant systems, namely on grid, hybrid and off grid. All the three have advantages and disadvantages [2]. According to the method of placing solar modules, solar power plants are divided into: ground-based solar power plants, rooftop solar power plants (located on flat, pitched and other types of roofs), facade solar power plants, BIPV solar power plants, solar carports, floating solar power plants, and mobile (or portable) solar power plants [9]. Installing a solar power plant requires an open space such as a rooftop for its installation so that it is hoped that the capture of solar radiation can be optimal [10].

In developed countries the utilization of solar energy into electrical energy through solar power plants is already very large. There has been a lot of research on the implementation of rooftop-based and on-grid solar power plants. His research results have also been widely published, including research reports [11–17]. From the report it is known that the main components of rooftop-based and on-grid solar power plants are solar panel modules, on-grid inverters, PV generation meters, and net meters.

In building a solar power plant, generally, it is first designed and simulated before a real solar power plant is built. The goal is to avoid wastage of costs due to construction errors. A number of computer software have been reported to be used for design and simulation. Among them are PVsyst, PVGIS, PV Watt, PVForm, SolarPro, PV-DesignPro [11,18].

Given the large number of buildings with large roofs in Indonesia, the potential for using rooftop-based electricity is enormous. Many building owners in Indonesia have implemented on-grid and rooftop-based solar power plants. There have also been apublication about on-grid and rooftop solar power plants [10].

However, there are still many buildings that have not used their roofs as places for solar power plants. On the other hand, the Indonesian government's program to accelerate the energy transition to environmentally friendly renewable energy needs support.

1.2 Solar power plant at Widya Mandala Surabaya Catholic University

The Widya Mandala Foundation is part of the Catholic church which is based in the Vatican and is also one of the institutions belonging to the Indonesian nation. The Widya Mandala Foundation is called upon to participate in realizing the Vatican's call and for Indonesian state policy as in [8]. For this reason, in 2021-2022 the Widya Mandala Foundation has built the on-grid rooftop solar power plant of more than 500 KWp spread across five campuses of Widya Mandala Surabaya Catholic University, namely the Dinoyo 42 Surabaya campus, the Dinoyo 48 campus, Surabaya, the Kalijudan campus, Surabaya, the Madiun campus. , and the Pakuwon City Surabaya campus.

This article intends to communicate the design and implementation of a 232.2 KWp rooftop and on grid Solar Power Plant located on Widya Mandala Surabaya Catholic University Pakuwon City campus. The purpose of the presentation is to present the results of the design and implementation, as well as the performance of the solar power plant. In the next sections of this article will be explained the design and implementation method, performance measurement, and implementation results of the solar power plant.

1.3 Solar power plant performance parameters

Parameter indicators to determine the performance of an on grid solar power plant system have been made by the International Energy Agency (IEA) [19].

According to the IEA, there are many parameters of solar power plant performance that reflect the overall solar power plant performance. Some of them are performance ratio, energy yield, resource yield, capacity utilization factor, inverter efficiency, system efficiency. Meanwhile. energy output, system efficiency, reference yield, final yield, performance ratio, annual capacity factor and CO2 emissions avoided are the elements of performance evaluated used by [19] in evaluation on grid PV system in Casablanca, Morocco. The Performance ratio is the ratio of the energy effectively produced (used), with respect to the energy which would be produced if the system was continuously working at its nominal STC efficiency. The PR is defined in the norm IEC EN 61724 [20].

2 Design and implementation method

In order to build the solar power plant in the Widya Mandala Catholic University Building, Pakuwon City campus, the following steps are taken: 1) Building data collection, 2) Design and simulation of the solar power plant with PVSyst software, 3) implementation, and 4) commissioning test.

2.1 Building data collection

To obtain the required building data as input for the design of an on-grid rooftop solar power plant, data was collected on the Pakuwon City campus building.

Based on the results of data collection, the Pakuwono City campus building has 10 floors including the roof. The roof area is 4280m2. Electrical power installed in the building of 1576KVA comes from grid utility. PT.PLN The building is located at -7.27 ºS latitude, 7m

altitude, 112.81 °E longitude, and UTC+7 time zone. Global irradiation at the location based on Meteonorm 8.0 (2010-2014) is 1916.4 kWh/m2/year.

2.2 Design and simulation with PVSyst

To design and simulate the required solar power plant PVSyst V7.2.8 software is used. As PVSyst input, the building data mentioned in 2.1 is used. To obtain the required number of solar panels, a solar panel module made by JA Solar model JA M72-S30-540MR with a power capacity of 540Wp per unit was used, while an inverter made by SMA model Sunny Tripower Core 2 was used to determine the number of inverters. The panel positions were placed in two orientations. Orientations 1 and 2 have a tilt/azimuth of 10/55° and 10/25° respectively.

Based on the data above, we obtained 430 PV modules with a total power of 232.2 KWp, 2 inverters with a total power of 220 kWac, and 8 arrays. The array arrangement, orientation, and connections to the inverter are shown in table 1.

Table 1. Array arrangement, orientation and connection to the inverter.

Array num-ber:	Num-ber of PV modu-le (unit)	Configura-tion	Orientation	Connected to inverter number:
1	34	2 strings 17 in series	1	1
2	72	4 strings 18 in series	1	1
3	90	5 strings 18 in series	2	1
4	19	1 strings 19 in series	2	1
5	34	2 strings 17 in series	2	2
6	72	4 strings 18 in series	2	2
7	90	5 strings 18 in series	1	2
8	19	1 strings 19 in series	1	2

2.3 Implementation

The results of the PVSyst 7.2.8 simulation are then implemented. For implementation, selected PV modules, inverters and KWh meters is used. Figure 1 shows the layout PV module array of the 232.2 KWp on grid rooftop solar power plant. The specification other system explained in 2.3.1 to 2.3.3.

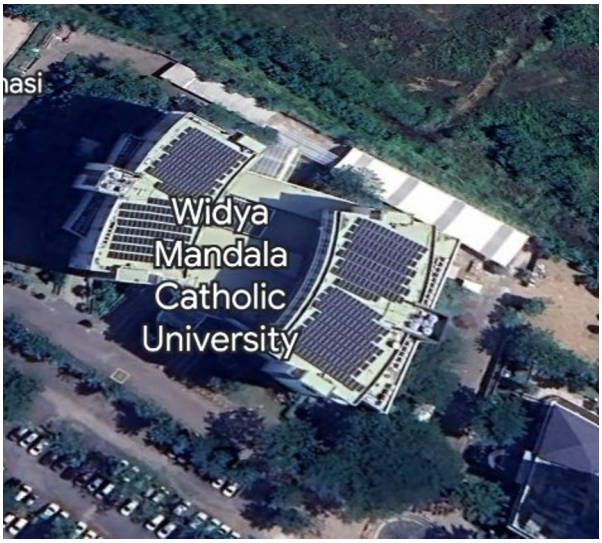

Fig. 1. Layout PV module array of 232.2 KWp rooftop and on grid Solar Power Plant located at WMSCU Pakuwon City campus.

2.3.1 PV module

This system uses 430 units of PV module, brand of JA Solar 540Wp, made in China. The specification of the module as shown in table 2.

Table 2. PV Module specification.

Category	**Specification**
Type	monocrystalline
Capacity	540Wp; 24V; 12,97A
Dimension	2279 x 1134 x 35 mm
Weight	28,6 kg
Efficiency	20,90%
Degradation	< 0,8%/year

The modules are placed on the rooftop of building A and building B of Pakuwon City Campus according to the configuration mentioned in table 1.

2.3.2 Inverter

The system uses 2 inverters, type of SMA Sunny Tripower Core 2 transformerless, made in Germany. Inverter is integrated with PV generation meter. The specification of the inverter as shown in table 3.

Table 3. Inverter specification.

Category	Specification
Capacity	110 kVA
Number of phase	3 phase/
Dimension	117 x 682 x 363 mm
Weight	93.5 kg
Input DC Voltage	500Vdc-800 Vdc
Rated AC Output Voltage	400Vac/230Vac
Frequency	50Hz
Efficiency	98,60%
Number of MPPT	12
Monitoring	SMA Data Manager

2.3.3 On grid meter

The system uses on grid meter made in PT EDMI Manufacturing Indonesia Cikarang provided by the grid utility. The specification of the meter is shown in table 4. This KWh meter serves to measure the amount of import and export power between solar power plant and utility grid.

Table 4. On grid KWh meter.

Category	Specification
Brand	EDMI
Type	Mk10E
Dimension	262mm x 175mm x 95mm
Weight	2 kg
Nominal voltage	3x 57.7/100V-3x230/400V
Nominal current	5(10)A
Frequency	50Hz
Number of phase	3P3W/3P4W
Class	0,5S
Monitoring	SMA Data Manager

Besides, the system uses aluminum extrusion material for mounting structure, Modbus function as communication protocol for Monitoring and Control Unit, one unit of AC combiner, DC side cable, AC side cable, grounding cable and cable management.

2.4 Commissioning test

To find out that the on rid of the solar power plant system has met the installation requirements, a commissioning test is held. For this reason, a list of parts of the installation that need to be checked is made.

The parts examined include PV modules, on grid inverters, Monitoring and Control Units, AC combiners, DC side cables, AC side cables, grounding cables, and cable management. The parts measured include the PV module strings output, inverter input and output, insulation resistance, and grounding resistance. It is found that three phase inverter output voltage (Voc) is around 410-413 V, and output current (Isc) is around 118-120A.

3 Performance measurement

The 232.2KWp on grid rooftop solar power plant has been established since May 11, 2022. To find out its performance, it is necessary to take a number of data by measurement. Data was taken for the period May 2002 to May 2023.

The tool used to measure and monitor the solar power plant is the SMA Energy Meter App version 1.19.173R. With this tool the performance of the solar power plant can be monitored and measured remotely every day. This application stores measurement data from the time it was founded until now.

Based on the data collected the solar power plant performance will be analysed.

4 Results and discussion

In this section will be presented measured data of 232,2 KWp Solar Power Plant that collected in period 2022 year from May to December and in period 2023 from January to May. Based on the data will be analyzed solar power plant performance using energy produced, reference yield, final yield, performance ratio, annual capacity factor , energy balance, and CO2 emissions avoided indicators.

4.1 Energy production

Figure 3 shows energy produce every month from May 2022 to May 2023. The figure also shows the expectation energy produced every month. Total energy produced from May to December 2022 is 221.788 MWh, while energy produced from January to May 2023 is 145,400 MWh.

From Figure 3 can be seen that total yield is closed with yield expectation. Factor that may influence this difference are weather and variability in sunlight intensity.

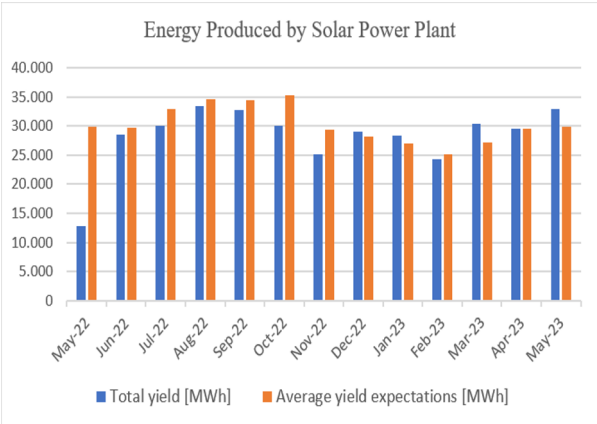

Fig. 3. Energy produced from May 2022 to May 2023.

4.2 Performance ratio

Based on PR definition and data shown in figure 3, the PR of the solar power plant from May 2022 to 2023 is 93% This figure is higher than PVSyt simulation output which is 80,99%. A high PR indicates that the solar power plant is operating effectively and efficiently.

4.3 Annual capacity factor

Capacity factor is defined as the actual electricity production divided by the maximum possible electricity output of a power plant, over a period of time [10].

According to PVSyst output, nominal energy produced at STC efficiency 20,9% will be 427,6 MWh, while total energy yield from May 2022 to 2023 367,188. So, the annual Capacity factor of the solar power plant from May 2022 to May 2023 is 85,8%. This value is less than performance ratio of the solar power plant. It is indicates that efficiency of the system in converting solar radiation into energy is high.

4.4 Energy balance

Energy balance an on grid solar power plant shows the amount energy produced by solar power plant, energy consumption, energy supplied from the grid utility and energy feed in to grid utility.

Figure 4 shows the monthly energy balance of the on grid solar power plant. From May 2022 until May 2023 total energy generation by the solar power plant is 367.188 MWh, energy supplied by grid utility to building is 1,525.788 MWh, total energy consumption in building is 1,877.661 MWh, energy fed into grid is 14,372 MWh. Energy produced by the solar power plant that directly consumed in building is 351.884 MW. This data shows that the solar power plant palys a role in reducing dependence on utility network by producing energy that can be used directly in building. Even though some energy is sold to the grid, total energy consumption in buildings is still exceeds the total energy produced by the solar power plant, so there is still dependence on supply from utility grid.

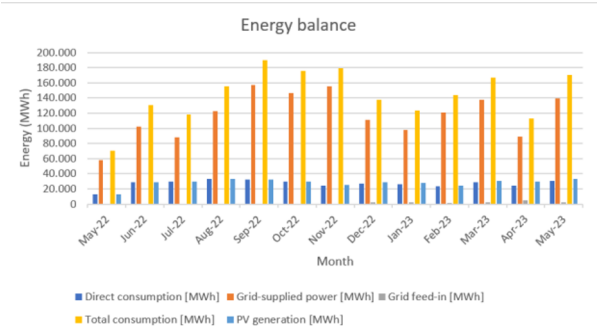

Fig. 4. Energy balance from May 2022 to May 2023.

4.5 CO2 avoided

Fossil fuel power plant will produce 0.6 kg CO2 emission per 1 kW electricity generated. Solar power plant make it possible to avid this emission when they are used to generate the same amount of electricity [21].

Figure 5 shows CO2 avoided by the on grid solar power plant. The amount of CO2 avoided increase or decrease proportional to amount electricity generated. Total CO2 avoided from May 2022 to May 2023 is 146.9 ton or 0,63 kg per kW.

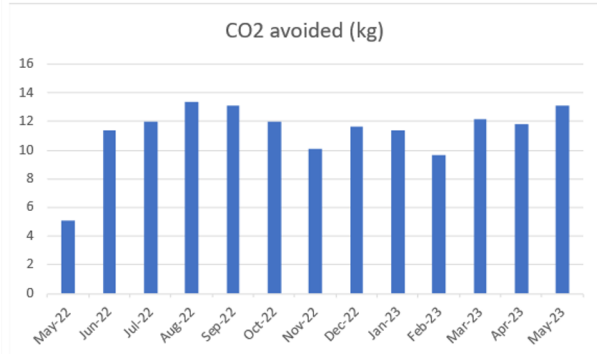

Fig. 5. CO2 avoided monthly by the solar power plant from May 2022 until May 2023.

Data shows that the amount of CO2 avoided increases or decreases in proportion on the amount of electrical energy produced by solar power plant. This is in accordance with the principle that the more energy produced by solar power plant, the more CO2 is avoided due to the reduction the use of fossil fuel-based energy.

Analysis of this data shows that the solar power plant plays an important role in reducing greenhouse gas emissions, especially CO2. In other words, the more energy produced by the solar power plant the greater its contribution to the environment and the efforts to reduce the impact of climate change. The high avoided CO2 per KW ratio also shows that the solar power plant has good efficiency in reducing carbon emissions.

5 Conclusion

In this article has been explained about design and implementation a 232,2 KWp on grid rooftop solar power plant located at Widya Mandala Surabaya Catholic University Pakuwon campus.

From the explanation can be concluded that the AC output of the solar power plants is three phase system and output voltage of inverter (Voc) is 410-413Volt, while current ouput (Isc) is 118-120A.

The performance of solar power plants is as follows: The total energy generated from May to December 2022 is 221,788 MWh, while the energy generated from January to May 2023 is 145,400 MWh, the PR of solar power plants from May 2022 to 2023 is 93%, factor The annual capacity of solar power plants from May 2022 to May 2023 is 85.8%, the energy fed into the grid is 14,372 MWh, and the Total CO2 avoided from May 2022 to May 2023 is 146.9 ton.

The implementation of 232,2 KWp Solar Power Plant is a significant step toward environmentally friendly energy. It also contributes to carbon footprint reduction and support sustainable development goal

There are so many performance parameters of solar power plant but in this article only partially discussed. Therefore, further studies on the performance of this solar power plant need to be done to find out its complete performance.

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