PERFORMANCE OF ROOFTOP PHOTOVOLTAIC SYSTEM WITH ADDITIONAL WATER COOLING SYSTEM

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Abstract

Improving solar power plant performance is considered quite important for existing and prospective users of rooftop solar power plants in Indonesia due to its unattractive economic value. One of the efforts to optimize the performance is the application of an additional cooling system on the plant's photovoltaic module. This study aimed to determine the effectiveness of temperature reduction of the applied cooling system on solar panel productivity. The research was performed on the existing rooftop solar power plant with a capacity of 3 kWp, located in Depok City with coordinates of 6°38'03.40" South Latitude and 106°82'03.49" East Longitude.

The results showed that the additional water cooling system with a closed-loop pumping method on the installed solar module's entire surface could improve the rooftop solar power plant performance with an average production increase of 15.7% in 7 days of study. Meanwhile, from an economic point of view, this cooling system installation payback period was 2 years.

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1. Introduction

A rooftop solar power plant is one of the small-scale solar power plants currently developed with a capacity of lesser than 25 kiloWatts (NREL, 2015). This system can reduce the electricity consumption or costs of the State Electricity Company. It generally positions solar modules on the roofs of houses, offices, schools, factories, and other buildings. Some of the features and advantages of rooftop solar power plants, compared to other solar power plant system applications, include (Adjat Sudrajat - BPPT, 2019)

1. It does not require additional land because the solar module is installed on the roof of the existing building, thus making the investment value cheaper;
2. Having access to direct sunlight because the solar module is installed on the roof, which is higher than other parts of a building.
3. Not interfering with daily activities since the installation does not interfere with the house or building landscape;
4. Relatively easy and cheap in its maintenance.
5. Easy to monitor automatically and online via a computer or smartphone.
6. Not requiring transmission and distribution costs because the installation is close to the customer and the electricity network because the customer is directly under the generator system.

An analysis using both software and manual calculations before the rooftop solar power plant installation is necessary for maintaining and increasing its economic value. It makes the design of the rooftop solar power plant better and optimal. The optimization value can be obtained by planning and selecting suitable components with high efficiencies like PV modules, inverters, batteries, controllers, and other equipment. The point of placement, position, and tilt against the sun, shading, and other mounting techniques also play an essential role in the optimization value (Bagus Ramadhani - GIZ GmbH, 2018).

For a rooftop solar power plant that has been installed, an analysis of its design and performance can also be carried out to provide feedback and find out what can be used as a reference. However, making changes to an installed solar power plant may be difficult. Another technique applicable to optimize a solar power plant is installing a cooling system to an installed PV module.

This research aimed to increase the installed solar power plant's economic value by adding an external cooling system to the PV module for its optimization. Several kinds of research related to the cooling system of PV module have been carried out previously, among them by (Palumbo, 2013), (Afriandi, 2017), (Haris Isyanto, 2017), and (Hasbi Assiddiq S, 2019). Still, all of these studies were done by using only individual solar cells or solar modules. Different from previous studies, this research was using an object of an integrated and installed solar power plant system, which has not been done in earlier research.

This research was carried out by installing a cooling system directly on an existing solar power plant. The test results were those obtained as a whole on the installed solar power plant system, not only limited to one individual solar cell or solar module. The addition of a cooling system to the PV module was expected to increase the solar power plant's optimization value or performance to increase electrical energy production and, in turn, reduce monthly electricity bills.

2. Methodology

a. Research Location

The research took place in one of the housing estates in Depok City, Jawa Barat, to be precise in the residential complex of Orchid Residence G/4. It lies at coordinates of 6°38'03.40" South Latitude and 106°82'03.49" East Longitude. Depok has a solar potential of 4.31 - 4.39 kwh/m^2/day (ESDM One Map, 2020). Figure 1 depicts the research location.

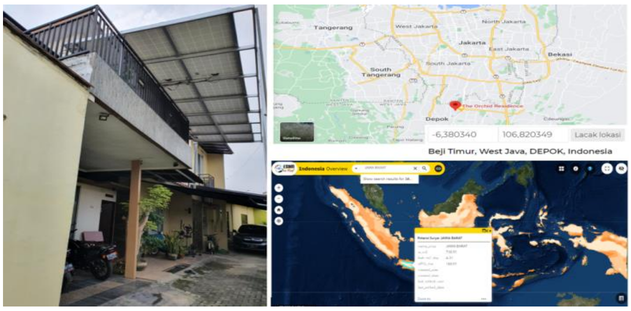

Figure 1. Research location

b. Research Object

The research object was a rooftop solar power plant with an on-grid type system. It operates parallel to the electricity grid of the State Electricity Company. The rooftop solar power plant, which has been installed and operated since July 2019, is a small-scale solar power plant with a capacity of 3 kWp. Its main components or devices include solar modules or PV panels, inverters, main electric panels, batteries (optional), Exim or Net Metering, utility grid or the State Electricity Company network, and loads. Following are the data and specifications of the rooftop solar power plant observed:

1. A roof top solar power plant with an on-grid system to the State Electricity Company network.
2. Containing nine photovoltaic panels branded *Canadian*, with a total capacity of 2985 Wp, consisting of 6 PV panels, each of which has a capacity of 330 Wp and 3 PV panels, each of which has a capacity of 335 Wp.
3. The inverter was a hybrid inverter branded *Kenika* with a capacity of 3.6 kW.
4. The solar power system was equipped with four batteries branded *Power fit* with 100 Ah ex 12 V specifications and a total capacity of 4 x 12 x 100 x 80% (Eff.) = 3840 Wh. These batteries did not function in an off-grid system. Still, they served as a backup energy storage medium to be used in emergency conditions: when the energy supply from the State Electricity Company is cut off, when solar panels stop producing at night, or when no solar radiation is available.
5. The solar power plant had Exim or Net Metering, which was integrated with the State Electricity Company network's on-grid system, allowing energy export when the solar panel exceeds the energy requirements used. The current scheme for exporting electrical energy to the State Electricity Company was 65% - 35%.

c. Research Stages and Flow

The stages of the research carried out include:

1. Performing research preparation, including collecting references regarding cooling systems and testing them, designing a cooling system installed directly on a rooftop-installed solar power plant, including preparing materials and tools required.
2. Installing a cooling system in the rooftop solar power plant, including testing and repairing of the cooling system.
3. Measuring data, parameters, and output power performance of the solar power plant when working with and without a cooling system.
4. Analyzing the solar power plant's performance for seven days of testing with and without cooling systems, performing comparative tests, and concluding, including economic analysis, reduced the electricity bills.

d. Cooling System Design

The cooling system final design in this study was not much different from its initial design. The following things are in the design of the cooling system in the installed solar power plant:

1. The cooling system in this study was an active cooling system using water pumped on the entire surface of the solar module on the installed rooftop solar power plant.
2. This cooling system was a closed-loop system, where the water used to cool the solar module would be channeled back through the return line gutter and stored in a reservoir where it will be pumped back and used as cooling water. The water flow rate was 30 liter per minute through 46 holes on a 6.92-meter length of ½ inches pipe with a 15-centimeter distance between each hole.
3. The cooling fluid medium used was groundwater or from Water Companies without a cooling fluid or coolant mixture.
4. This cooling system was permanent and applicable to the installed rooftop solar power plant, which can be used immediately during and after the research.

The cooling system's final design image can be seen in Figure 2, while the final results of the installation are available in Figure 3.

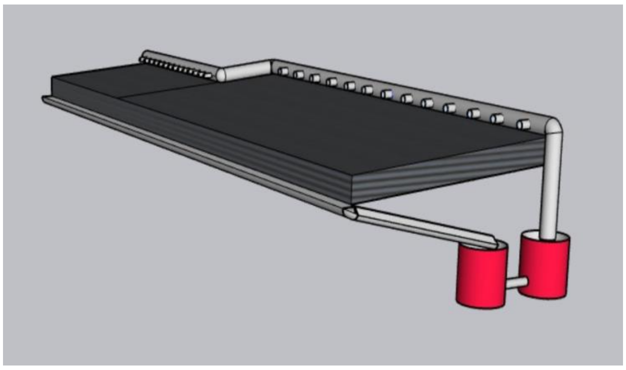

Figure 2. 3D View of PV module cooling system design

Figure 3. Installed cooling system

e. Testing Time

The test was carried out several days from the end of September to early October with almost the same solar radiation, not cloudy or rainy. Only seven among those days met the desired criteria, namely 18, 19, 24, 28, September 30, and 1, October 2, 2020. The test was carried out by collecting data several times between 7 am and 5 pm. The test to obtain comparative data was carried out by taking the solar power plant productivity data by conditioning it to work with and without a cooling system every 1 hour of the research time range.

f. Water and Electricity Consumption of the Cooling System

Besides the costs needed in the cooling system's initial installation, the solar power plant cooling system's day-to-day operation also requires at least two daily needs: water as a cooling media source and electricity to run the water pump. One of this system's advantages is the closed-loop system in which water that has been used for the process is collected and reused as the cooling media. It just needs a small amount of water: 900 liters for 30 days.

Based on the water level provided by the Regional Water Utility Company at the 2020 Special Capital Region of Jakarta (DKI Jakarta), it just costs Rp5.400,00 per month. This cooling system operation needs electrical energy to run a water pump. Operating for 8 hours in one day for 30 days makes it consume electricity as much as 20.75 kWh or about Rp30.000,00.

3. Results and Discussion

a. Cooling System Effectiveness

Based on the processing of the rooftop solar power plant's data and research parameters when working with and without a cooling system. Several research results were obtained, including the average value of solar radiation or irradiation. The average temperature of solar panel, the comparison of the maximum production values, and the comparison of the average PV production values, and the effect of adding a cooling system to a solar power plant on monthly electricity costs. This study's moderate solar radiation intensity was taken from measurements in seven days of research, from 6 am to 6 pm, divided into 12 periods (hourly) a day. The measurements were taken with a portable pyranometer where the rooftop solar power plant was installed. The average solar radiation intensity from the test results can be seen in Figure 4.

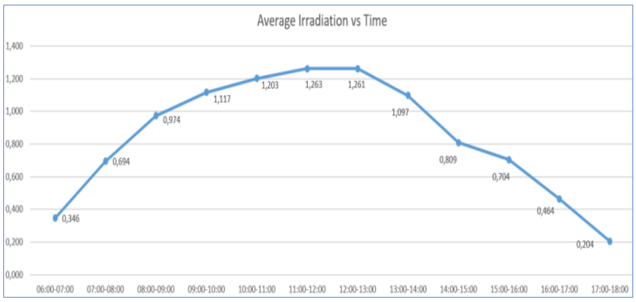

Figure 4. Chart of average irradiation (y) vs. time (x)

Simultaneously, the solar panel surface was measured for its temperature change during its operation using with and without a cooling system considering that the cooling system operated only from 7 am to 5 pm. Data of the solar panel temperature change when working with and without a cooling system can be seen in Figure 5.

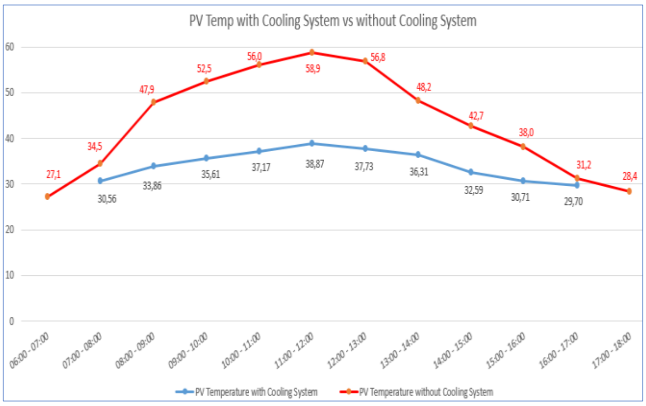

Figure 5. Chart of PV surface temperature (y) with and without cooling system

The data and chart above show that the most significant difference of 20°C or 34% in the average temperature occurred when the cooling system operated between 11 and 12 am. Comparing the solar power plant's maximum production values when working with and without a cooling system was a qualitative test aimed to test the hypothesis, which stated that the cooling system would increase the solar power plant's production. The test was performed by observing the inverter's maximum production values when the cooling system was turned on and when turned off, respectively.

The values displayed mean the highest production values during the seven days of the study when the solar power plant worked with and without a cooling system, respectively. The comparison of the PV production values when the solar power plant worked with and without a cooling system can be seen in Figure 6.

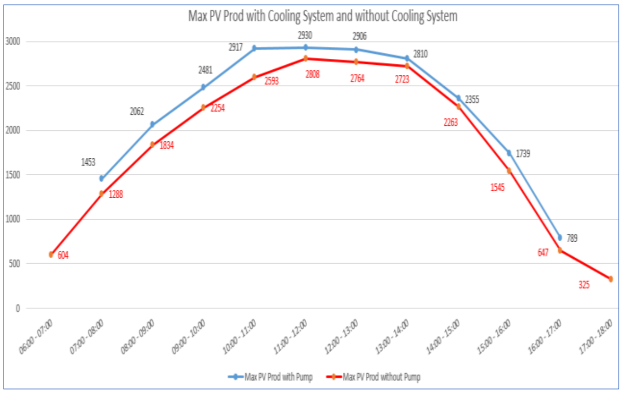

Figure 6. Charts of maximum PV production values (y) when solar power plants work with and without cooling system

The comparison of the average production values in the time ranges is set of the utmost importance. In addition to proving the hypothesis of cooling systems' effect on solar module's performance, a comparative test illustrated how significant the difference in solar power production when working with a cooling system compared to without a cooling system was. The data analyzed was data on the average production values of the solar power plant in each time range on each date included in the seven days of the study. The average value of the solar power plant' production was taken from the installed inverter's readable data. The detailed data can be seen in Figure 7, which compares the two conditions' values.

Based on the data on the average production values when the solar power plant worked with and without a cooling system, the quantitative value of the increase in the solar Power's production could be calculated. By considering the differences in solar radiation intensity and temperature, qualitative calculations and analysis were only carried out for the solar power plant's production from 7 am to 4 pm. Table 1 shows the increase in the solar power plant's average production value when working with a cooling system during the seven days of the study and at the predetermined hour was 15.7%.

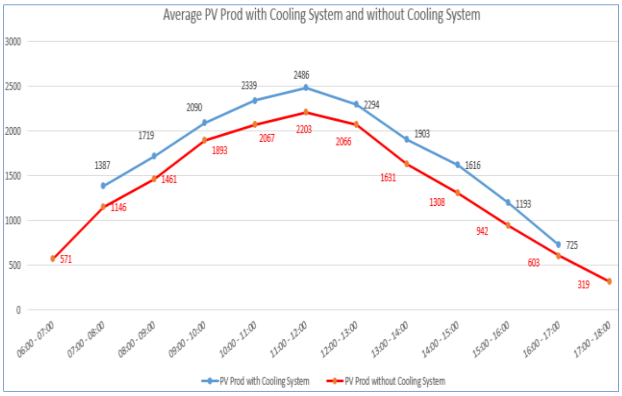

Figure 7. Charts of average PV production (y) when solar power plants work with and without cooling system

Table 1. Increase in PV Production when working with cooling system

Range of Time	Average Prod. without Cooling System	Average Prod. with Cooling System	PV Production Increament in (W)	PV Production Increament in (%)
06:00 - 07:00	571,1	No Pump	-	-
07:00 - 08:00	1146,4	1386,9	240,4	21,0
08:00 - 09:00	1461,1	1718,6	257,4	17,6
09:00 - 10:00	1893,0	2090,4	197,4	10,4
10:00 - 11:00	2067,4	2339,1	271,7	13,1
11:00 - 12:00	2202,7	2486,3	283,6	12,9
12:00 - 13:00	2066,0	2293,6	227,6	11,0
13:00 - 14:00	1630,6	1903,0	272,4	16,7
14:00 - 15:00	1308,1	1616,4	308,3	23,6
15:00 - 16:00	942,1	1192,6	250,5	26,6
16:00 - 17:00	603,0	725,3	-	-
17:00 - 18:00	318,7	No Pump	-	-
Average Production without Cooling System (07:00-16:00)			1635,3	**Watt**
Average Production with Cooling System (07:00-16:00)			1891,9	**Watt**
Average PV Production Increament			256,6	15,7

b. The economic overview of the cooling system

This cooling system manufacturing was carried out in 3 days for tools and materials preparation, cooling system lines installment and pump assembly, system performance test, and minor repair. The manufacture costed Rp3.500.000,00. Based on the average monthly electricity bill before and after the cooling system utilization, the economic value obtained was Rp142.987,00. It was acquired by calculating the monthly electricity bills and water and electricity consumption as operational costs. The cooling system was run for 8 hours from 7 am to 4 pm all days during October and November 2020 for this economic review. The Pay Back Period (PBP) of the investment cost of manufacturing this cooling system divided by the monetary value obtained was two years. The detailed costs of this cooling system can be seen in Table 2.

Table 2. Costs of cooling system installation

No	Needs		Amount	Cost
	Material and Equipment	Work Cost		
1	PVC Gutters		4 pieces	270,000
2	Gutter hubs, socks, and hangers		6 + 4 + 10 pieces	127,000
3	Gutter cover and funnel		6 + 3 pieces	144,000
4	Lumber 5 x 10		1 piece	90,000
5	Steel beam		1 piece	70,000
6	Mild steel nuts		50 pieces	13,500
7	2" PVC pipe + knee + PVC glue		2 + 6 + 4 pieces	213,000
8	½ PVC pipe + knee		2 + 4 pieces	65,000
9	Carpet		2 meters	21,000
10	Sealant and pump		1 set	70,000
11	Drill bit		2 pieces	32,000
12	28 water nuts and 50 steel nuts		2 sets	46,000
13		Labor cost	2 people x 3 days	900,000
14		Scaffolding rent	3 days	210,000
15	Submersible pump 80 Watt, Head: 2-3 meter, Cap: 24-36 l/m		1 unit	470,000
16	Energy meter + electric cable + socket		1 set	275,000
17	Large buckets		2 pieces	170,000
18	Additional Cost, etc.			300,000
Total Cost				**Rp 3,486,500**

4. Conclusion

The cooling system design by pumping water to the installed PV module's entire surface with a closed-loop water circulation system is quite good for a canopy-shaped rooftop solar power plant. Meanwhile, for rooftop solar power plants mounted to the roof tile, installing and manufacturing a closed-loop system is problematic. The cooling system was found to decrease the solar module temperature by more than 10 % during the time range from 7 am to 4 pm. Beyond this range, the decrease was less than 10%. Thus, the cooling system pump was supposed to be turned on only in the time range from 7 am to 4 pm.

When the PV module worked with the cooling system in the same time range in 7 research days, the solar power plant's maximum production value was always more significant than that without the cooling system. The hypothesis that the solar module cooling system can increase the solar power plant's production can be proven in this study. Qualitatively, the cooling system on the rooftop solar power plant at the author's house increased the solar power plant's production. Likewise, the solar power plant's average production value when the PV module worked with the cooling system was always more significant than that without the cooling system.

Besides providing qualitative proof, testing this average production value could also provide a quantitative calculation of the increase in production. From the comparative test on seven days of research, namely 18, 19, 24, 28, and 30 of September and 1 and 2 of October 2020, it was found that the increase in the average production of the solar power plant with the addition of the cooling system was 15.7 %. The economic value obtained by adding a cooling system on the rooftop solar plant was Rp142.987,00. The Pay Back Period (PBP) value of the cooling system was two years.

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