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Feasibility and Design of Grid-connected Floating PVs in West Java, Indonesia

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Abstract— Dalam Rangka upaya mendukung pengembangan energi terbarukan dan pembangunan pembangkit bebas fosil di berbagai wilayah di Indonesia dengan pemanfaatan bendungan di Jawa Barat sebagai tempat dengan potensi PV apung saat ini. Makalah ini mendiskusikan suatu pemodelan dan perancangan dari PLTS terapung terhubung jaringan. Desain Jenis PLTS terapung diusulkan masing - masing berkapasitas 1 MW Terhubung jaringan di tiga lokasi yang berbeda yaitu di bendungan Saguling, Cirata, dan Jatiluhur. Pemodelan meliputi potensi energi matahari menggunakan dan optimasi desain kapasitas komponen dalam sistem tersebut menggunakan beberapa perangkat lunak pendukung yang handal. Hasil pemodelan dan simulasi menunjukan potensi energi listrik masing- masing yang disalurkan ke jaringan PLN bendungan Saguling sebesar 1705.2 MWh/tahun, Cirata sebesar 1635,4 MWh/tahun, dan Jatiluhur sebesar 1611,8 MWh/tahun dengan *performance ratio* rata - rata 0.74 hingga 0.75. Total kapasitas masing - masing PV untuk setiap bendungan sebesar 1197 Wp masing - masing 550 Wp/PV panel dengan efisiensi 21,51%/PV panel dan 4 Inverter untuk interkoneksi ke jaringan PLN 544 Unit PV/array. Estimasi luas area untuk pembangunan sistem ini adalah 5561 m^2.

Kata Kunci: Cirata, Jatiluhur, PLTS terapung, *performance ratio*, Saguling

Abstrak— The modeling and design of grid-connected floating photovoltaic (PV) are covered in this paper. Using dams in West Java as a location with present floating PV potential, this paper encourages the development of renewable energy and the construction of fossil-free power plants in various parts of Indonesia. Three alternative locations—the Saguling, Cirata, and Jatiluhur dams—are proposed for floating-PV type designs, each having a capacity of 1 MW grid-connected. The modeling process uses a variety of dependable auxiliary software to simulate possible solar energy use as well as capacity design optimization of system components. Modeling and simulation findings indicate that the grids of the Saguling, Cirata, and Jatiluhur dam have a combined potential for electrical energy of 1705.2 MWh/year, 1635.4 MWh/year, and 1611.8 MWh/year, respectively, with an average performance ratio of 0.74 to 0.75. The total PV capacity for each dam is 1197 Wp, using 550 Wp/PV panel with an efficiency 21.51%/PV and 4 Inverters for grid connectivity. There are 544 PV units per array. 5561 m^2 is the estimated area needed to build this system.

Keyword: ***Cirata, floating PV, Jatiluhur, performance ratio, Saguling***

I. INTRODUCTION

It is necessary to keep enhancing the use of renewable energy to support electrical sources[1]. Construction of photovoltaic (PV) in diverse Indonesian locations is one of the attempts[2][3]. According to the Indonesia Energy Outlook 2020, In 2020, renewable energy made up 12% of all installed capacity. This is divided equally between hydropower (including big power plants) and other renewable sources of energy. In 2020, Indonesia generated 275 TWh of on-grid electricity annually, a decrease of more than 1% from 2019. A little over 65% of this was produced by PLN-owned assets, with the remaining percentage coming from Private Power Utilities (PPUs). RUPTL 2021-2030 predicts that between 2021 and 2030, total energy generation would rise from 291 TWh to 445 TWh, growing by an average of 4.9% year. Even though it will decrease from over 67% in 2021 to 59.4% by 2030, coal would still make up the majority of Indonesia's total electricity production[4].

Several studies on floating PV have been conducted and are interrelated including the study conducted by [5] which presents the ± 13% that can be utilized from all reservoirs in Bangladesh. Brazil's projected hybrid 180 kWp floating PV installation and hydroelectric power plant is capable of 40MWh/day of energy export to the grid[6]. An automated structure plan with a sizable capacity for 1 MW floating PV type construction was also created in South Korea at the same time[7]. Following significant improvements in previous years, Hapcheon Lake hosted feasibility tests and the installation of 100 kW and 500 kW floating PV systems[8][9].

However, various essential feasibility assessments are required for the construction of a floating PV[10][11]. When potential solar energy and other environmental conditions are examined, the availability of a location as a medium is required. For additional study, and the recommendations provided in this research model are listed in Table 1.

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Table 1. Literature review on floating PV development

No	References	Location	Proposed Design
1	S. Gurfude, C. Bhavtha, D. Tanusha, et al. 2020[12].	Analysis and design of a planned 1 MWp floating PV system in Nagpur, Maharashtra, India.	For the selected location, energy generation and electricity costs are estimated to be around 1614 MWh per year and 3 INR/kWh.
2	J. Suh, Y. Jang, Y. Choi. 2020[13].	Floating PV system in the Hapcheon Dam, South Korea.	Comparison of Observed and Estimated Electric Power Output from Floating Photovoltaic Systems.
3	M. Lopez, N. Rodriguez, G. Iglesias. 2020[14].	Asturias is a coastal region in Northern Spain with about 300 kilometers of coastline.	Combining floating offshore wind with solar PV results in a Power Smoothing index of up to 63% (hybrid System).
4	S. Makhija, S. Dubey, et al. 2021[15]	Narayanpur is a district in the Indian state of Chhattisgarh.	Analysis of Floating PV/On-Ground PV/Grid Extension Systems for Remote Area Electrification.
5	A. El Hammouni, A. Chalh, A. Allouhi, et al. 2021[16]	Fez, Morocco. Africa.	Floating PV generates up to 2.33% more daily energy than Overland PV, according to the design and construction of a test bench to investigate the potential of Floating PV systems.
6	S. Golroodbari, D. Vaartjes, et al. 2021[17]	Case study wind farm Borssele, Belgium.	Integration of offshore floating photovoltaic solar technology inside an offshore wind park feasibility study.
7	A. Ghigo, et al. 2022[18]	The Case Study of Lampedusa, Italy.	Floating Photovoltaic System Design and Analysis for Offshore Installation.

Table 2. Proposed location and coordinates

No	Dam	Coordinates	Location
1	Saguling	-06.913493° south latitude and 107.370737° east longitude.	Saguling, West Bandung Regency.
2	Cirata	-06.7003° south latitude and 107.3644° east longitude.	Plered Subdistrict, Purwakarta Regency.
3	Jatiluhur	-06.913493° south latitude and 107.370737° east longitude.	Jatiluhur, Purwakarta Regency.

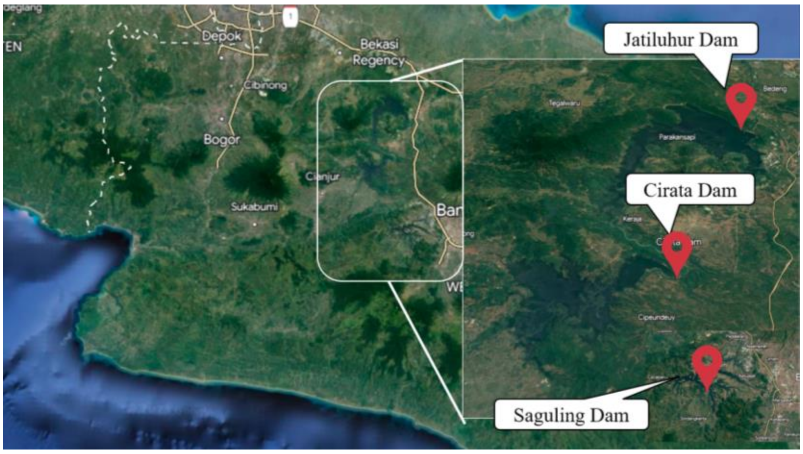

Figure 1. The location of three dams in West Java, Indonesia

Against the background of the aforementioned study motives, this work is proposed to investigate the renewable energy potential of solar cells found in the dams of Saguling, Cirata, and Jatiluhur. Determine the capacity and effective area of PV-based generation components. Modeling and optimizing the design of PV-based power plants, including loss analysis data, and delivering electrical energy to the utility grid by floating PV systems.

Session I (introduction), describes the relevant work that drove the objective of this study, whereas session II (methods) describes the design activities and modeling steps followed. Furthermore, in session III, the results and discussions obtained are described, followed by a conclusion in session IV.

II. METHOD

Details of the process, including location, energy potential, and floating PV design planning, are further detailed in this section. Furthermore, several possibilities for component technical data will be examined.

A. Location of Floating PVs Plant

This study's modeling and analysis were carried out in three separate sites. The first is Saguling dam, which is located at an elevation of 643 meters above sea level in West Bandung Regency, West Java, Indonesia. This reservoir is one of three dams that control the flow of the Citarum River, West Java's major river. The Jatiluhur dam is the second. This dam's inundation area is approximately 5,600 Hectares, with an initial storage volume of 875 million m^3 of water. Cirata dam, located in Cadas Sari Village, Tegal Waru Plered Subdistrict, Purwakarta Regency, West Java Province, was the site of the third research modeling and analysis. The Citarum River is used to generate hydroelectric electricity. This dam is Southeast Asia's largest hydroelectric power plant, electrifying the islands of Java and Bali with an annual capacity of 1,428 GWh, which is then channeled through a 500 kV high-voltage transmission interconnection for the islands of Java, Madura, and Bali, known as Jamali. Figure 1 depicts the location of three nearby dams in three different

Figure 2. Proposed of floating PV site at Saguling Dam

Figure 3. Proposed of floating PV site at Cirata Dam

Figure 4. Proposed of floating PV site at Jatiluhur Dam

districts of West Java and see Figure 2 until Figure 4 and Table 2 for detail coordinate location.

B. Energy Potential Data

The physics of a PV site must consider the site's energy potential. Meteonorm and PVsyst 7.2.12 support applications, in particular for meteorological data. Saguling Dam has an average Global Horizontal Irradiance (GHI) value of 155.9 kWh/m^2/month, with the maximum value of GHI occurring in October at 179.6 kWh/m^2/month and the lowest value of GHI occurring in January at 142.2 kWh/m^2/month, for a total value of GHI in one year of 1871.7 kWh/m^2/month. The Saguling region has an annual average temperature of 21.6°C, with an annual average wind speed of 1.1 m/second. Cirata dam has an average GHI value of 149.9 kWh/m^2/month over a year, with a total GHI value of 1799.7 kWh/m^2/year. The yearly average temperature is 23.1°C. Jatiluhur has an average GHI of 148.23 kWh/m^2/month, with a high GHI of 172.6 kWh/m^2/month in October and a total GHI of 1778.8 kWh/m^2/month in one year with the same average wind speed as the Saguling and Cirata dam.

C. Systems Capacity Design

A research flow chart should be used to clarify the study's progress. Figure 5 depicts the processes and methods of data gathering, from observation, simulation parameters through calculating the capacity of design components.

The first step, collecting data on GHI, air temperature, and wind speed at the three research locations. The coordinate point data of each research location is obtained from google earth software then the coordinate point data is entered in the moteonorm 8 feature in the PVsyst 7.2 software[19]. After the data is obtained, the floating PV capacity planning is carried out. Following the determination of the floating PV

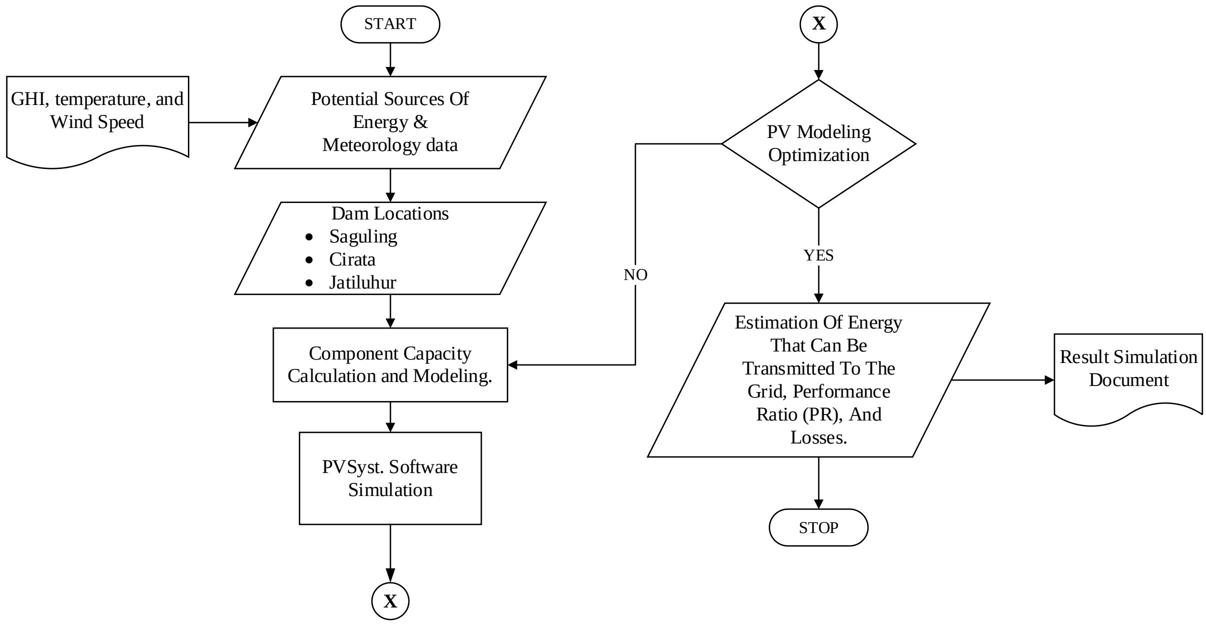

Figure 5. Modeling simulation method

capacity planning, the next step is to calculate the PV panel capacity, the type of PV panel, and the capacity of the inverter to be used, as well as the PV system voltage and nominal current in the PV system, in order to calculate the effective area for storing PV panels. Following the determination of the parameter data and PV system design, the next step is to optimize the PV system by varying the tilt or azzimuth of the PV panels, or by optimizing the PV panel system voltage, which becomes the input voltage of the inverter, in order to reduce DC wiring losses in the PV panel system, or by optimizing the Detail Losses parameters. The final stage is to assess the grid energy data, PV losses data, and the recommended PV performance ratio.

Several criteria influence the capacity analysis of a floating PV system, the first of which is the efficiency of the PV panel[20]. This is the amount of solar energy that the PV can capture and convert into electricity (see Equation (1) below).

$$\eta = \frac{P_{max}}{A\ (PV) x\ I_{rr}} x\ 100\% \quad (1)$$

PV panel capacity is calculated in this simulation using a PV capacity of 1000 kW. Equation (2) explains how to calculate the number of PV panels. Where N is the total number of pieces or units required.

$$N_{PV} = \frac{PV\ Cap\_tot\ (Wp)}{Wp/PV} \quad (2)$$

The calculation of the space solely for the placement of PV panels excludes the area required for easy installation and maintenance, as well as land for power homes and other structures. The needed data is the PV panel's efficiency value, which is derived based on the specified PV panel specs. See also Equation (3).

$$Area\ (m^2) = N_{PV_{panel}} \times Size_{PV_{panel}} \quad (3)$$

The inverter capacity calculation is modified to account for the required power. Apply Equation (4).

$$N_{Inv} = \frac{AC_{Power}(kW)}{Cap_{Inv}(kW)} \quad (4)$$

The DC:AC ratio is calculated using the PV power at Standard Test Conditions or STC (approx. 1,000/m2 and 25°C), and the PV power is determined by the inverter capacity. The DC:AC ratio is the ratio between the PV panels and the inverter. While the typical DC:AC ratio is 1.25, the DC:AC ratio of PV varies between 1.15 and 1.4. See Equation (5) for further information.

$$DC : AC_{ratio} = \frac{PV_{Power}(kW)}{Cap_{Inv}(kW)} \quad (5)$$

The performance ratio calculation demonstrates the efficiency of PV, which is computed by comparing the energy produced each year to the energy produced when the PV is fully operational. Equation (6) is used to calculate the PV performance ratio.

$$PR = YF/YR \quad (6)$$

Table 3. PV panels specifications

No	Technical Data	Parameters
1	Brand/Type	Longi-LR-72 HIH 550M
2	Op. Max. Power (Pmax)	550 Wp
3	Current at Max. (Imp)	13.120 A
4	Voltage at Max. (Vmp)	41.95 V
5	Short Circuit Current (Isc)	13.980 A
6	Open Circuit Volt. (Voc)	50.60 V
7	Weight	20 kg

No	Technical Data	Parameters
8	Max. Syst. Voltage (Vdc)	1500 VDC
9	Panel PV Size per pcs	2.256 x 1.133 m^2

Table 4. Inverter specifications

No	Technical Data	Parameters
1	Brand/Type	ABB-PV-S800-57-250kW
2	Max DC Input Power	250 Wp
3	Max PV Open-circuit	1000 Vdc
4	Max PV Array Input	600 A
5	DC Input Volt. Range	0 - 1000 Vdc
6	MPPT Volt. Range	450 - 1000 Vdc
7	Rated Output Power	20 kg
8	Op. Volt. Range	1500 VDC
9	Op. Frequency (Hz)	2.256 x 1.133 m^2
10	Max. Efficiency (%)	98.02%

The PV panel voltage is calculated based on the voltage magnitude in the technical data (Table 3-4), where this value will be the inverter's input voltage, with a voltage range on the inverter of 450 VDC and a maximum of 825 VDC, and the proposed system voltage is made using Equation (6).

$$Volt.Syst_{PV} = PV_{Volt} \times Serial\ Circuit_{PV}. \quad (6)$$

The voltage of the PV panel system is calculated to be 713.15 Vdc because it adjusts to the optimization of the number of PV panels utilized; with a total of 1197 units, the optimal voltage of each inverter input is 713.15 Vdc. The nominal current of the PV panel must be computed since it is related to the PV panel circuit, which will be calculated along with the system circuit. The current will be estimated using the current flowing in the inverter with a voltage of 713.15 Vdc and an inverter power capacity of 250 kWac, as shown in Equation (7) and the maximum inverter input current from the array in Equation (8).

$$Input\ Current_{InV} = \frac{Power_{Inv}}{Input\ Volt_{Inv}} \quad (7)$$

$$Imax_{Inv} = I_{PV} \times N\_PV_{parallel} \quad (8)$$

Table 5. System calculation results

No	PV System Calculation	Information
1	PV Efficiency (η)	21.51%
2	PV Qty (unit)	2176 unit
3	Area (m^2)	5561 m^2
4	Inverter Qty. (unit)	4 Unit
5	DC:AC Ratio	1.2
6	Performance Ratio	0.749
7	PV System Voltage (V_{DC})	713.15 V_{DC}
8	Inverter Input Current (A)	350.55 A
9	Max. Input Current of the Inv. (A)	419.84 A
10	Power Max. Inv. (Array)	299.55 kW
11	PV capacity of each inverter (unit)	544 Unit
12	PV Series circuit	17 Unit
13	PV Parallel circuit	32 Unit

Table 6. Horizon simulation results

Orientation and Horizon	Dam		
	Saguling	Cirata	Jatiluhur
Field type	Fixed plane	Fixed plane	Fixed plane
Tilt/Azimuth	11/0°	11/0°	11/0°
Av. Height	8.8°	7.2°	2.6°
Near Shading	No	No	No

When the PV panels are assembled in parallel and subsequently in series for input to the inverter, a string topology with four arrays for four inverter units is used to calculate the PV panel system circuit. The PV system voltage is set to the inverter's voltage capacity, which is between 450 and 825 Vdc. Equation (9) contains the number of PVs per inverter.

$$N_{PV/Inv} = \frac{N_{total}PV}{N_{Inv}} \quad (9)$$

The PV system voltage is set to the inverter's voltage capacity, which is between 450 and 825 Vdc. Equation (9) contains the number of PVs per inverter.

III. RESULT AND DISCUSSION

A. PV System Component Capacity

PV panel characteristics are stated in (Wp) and measured using the STC standard. Table 5 shows the floating PV system derived using Equations (1)-(9). This study's inverter has a capacity of 250 kWac. Strings of four inverters are utilized to support a PV capacity of 1 MW with a DC/AC ratio of 1.2.

Solar panel efficiency is a measure of how much solar energy the panel can convert into usable electricity using equation (1).

$$\eta = \frac{550\ Wp}{2556\ m^2 x\ 1\ kW/m^2} x\ 100\% = 21{,}51\%$$

After determining the PV capacity to be simulated in this simulation, a PV capacity of 1000 kWAC is determined, following Eq. (2).

$$N_{PV} = \frac{1197\ Wp}{0.550\ Wp} = 2176\ unit$$

The needed data is the PV panel's efficiency value, which is derived based on the intended solar panel specs, using Eq. (3)

$$Area\ (m^2) = 2176 \times (2.256\ \times 1.133)$$

$$Area\ (m^2) = 2176 \times (2.556) = 5561$$

The number of inverters with an inverter capacity of 250 kW per Unit, then the result of Eq. (4) is

$$N_{Inv} = \frac{1000\ kW}{250\ kW} = 4\ Unit$$

Table 5 shows that the number of inverters used is between 4 inverter units. The ratio between the PV panels and the inverter is called DC:AC ratio using PVsyst in Eq. (5).

$$DC : AC_{ratio} = \frac{1197\ kW}{1000\ kWAC} = 1.197$$

The magnitude of the PV panel system voltage will be made according to the inverter voltage capacity with Eq. (6).

$$Volt.Syst_{PV} = 41.95\ V_{DC} \times 17\ panel\ PV$$

$$Volt.Syst_{PV} = 713.15\ V_{DC}$$

Using equation (7), the outputs of this computation will determine the current flowing in the inverter with a known voltage of 713.15 VDC and a power capacity of 250 kWAC.

$$Input\ Current_{InV} = \frac{250\ kW}{713{,}15\ V_{DC}} = 350.55\ A$$

The maximum input current of the inverter from the array The maximum power of the inverter from the array is generated by Eq. (8).

$$Imax_{Inv} = 13.120\ A \times 32\ unit = 419.84\ A$$

with a maximum power where the PV array voltage multiplied by the PV array current is 299.55 kWDC. The PV system voltage is adjusted to the capacity or voltage range of the inverter, which is a minimum voltage of 450 VDC and a maximum of 825 VDC, with the number of PVs per inverter using Eq. (9).

$$N_{PV/Inv} = \frac{2176\ unit}{4\ unit} = 544\ unit$$

B. PV Simulation Result and Characteristics

Floating PV simulation and modeling generate data such as characteristics such as general parameters of PV position towards the sun and average energy harvesting to energy output.

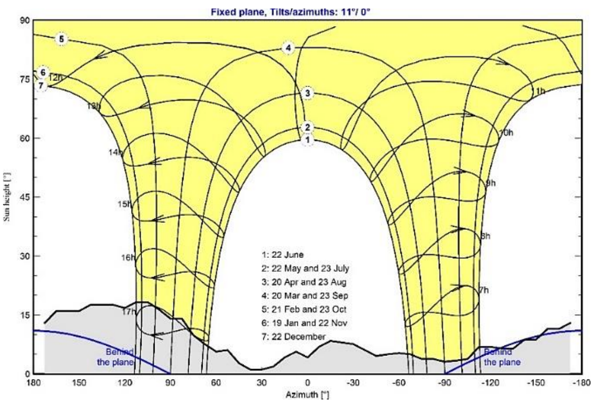

Figure 6. Saguling sun paths (height/azimuth diagram)

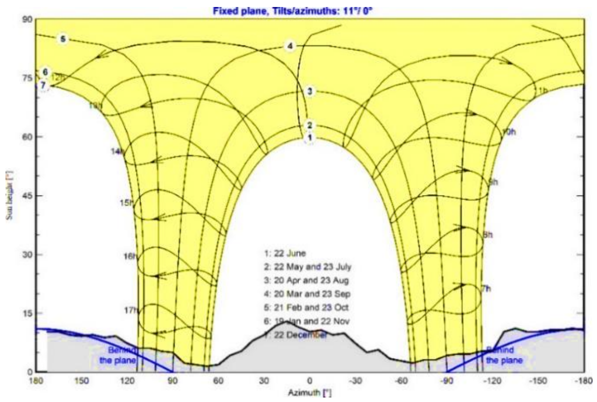

Figure 7. Cirata sun paths (height/azimuth diagram)

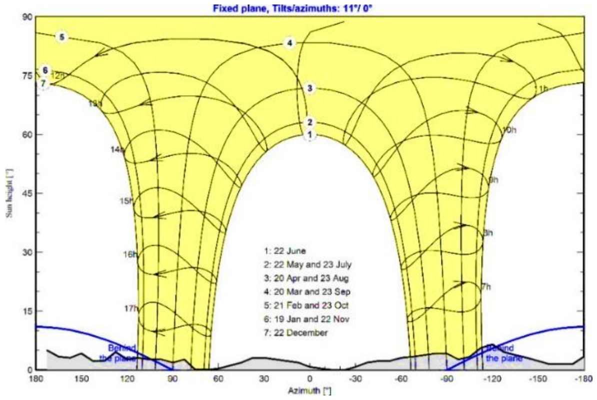

Figure 8. Jatiluhur sun paths (height/azimuth diagram)

Table 7. Energy production simulation results

Average/Yr Energy production	Dam		
	Saguling	Cirata	Jatiluhur
Glob. Hor. (kWh/m^2)	1871.8	1799.7	1778.9
Diff.Hor. (kWh/m^2)	868.74	924.34	951.87
T. Amb (°C)	21.58	23.09	25.07
Glob. Inc. (kWh/m^2)	1898.9	1822.6	1797.1
Glo. Eff. (kWh/m^2)	1788.3	1719.2	1705.1
E. Array MWh	1816.5	1743.3	1719.3
E. Grid MWh	1705.2	1635.4	1611.8
Perf. Ratio	0.75	0.75	0.749

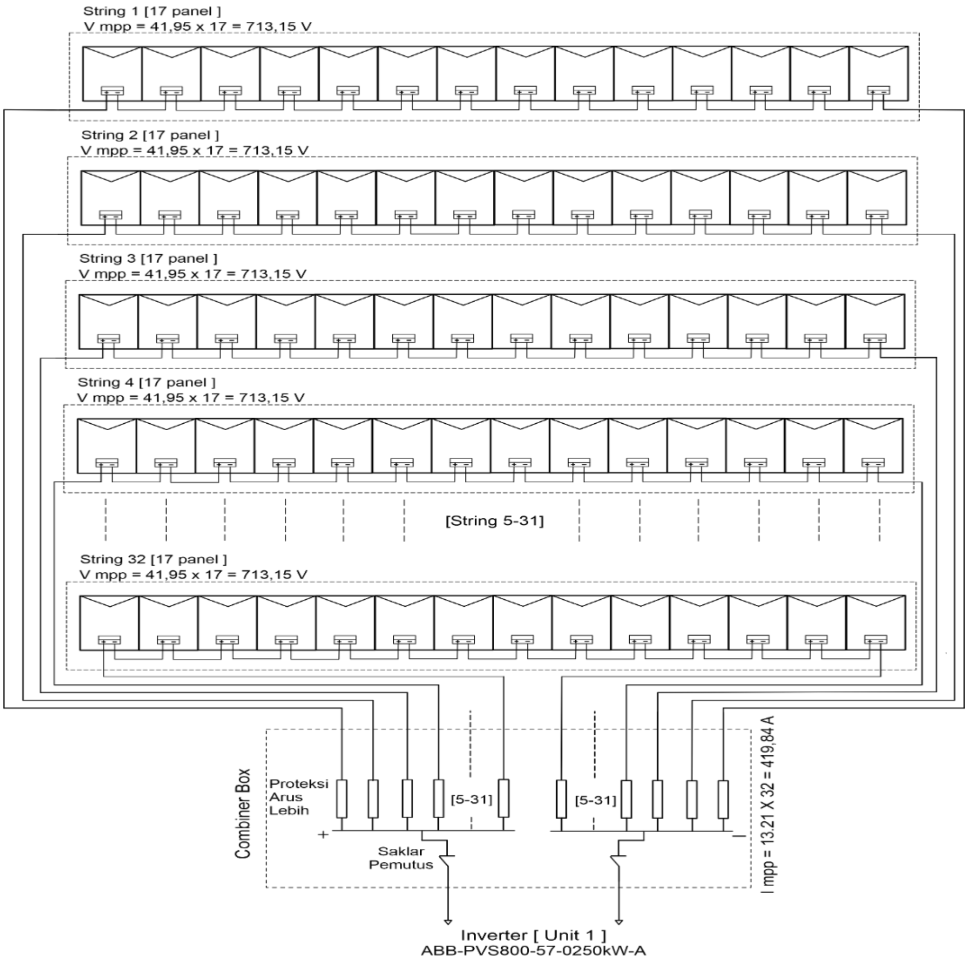

Figure 9. PV module circuit per-Unit inverter

This Losses Detail section describes the many types of losses in the simulated PV system. The losses in the three simulated floating PV systems are the same, however there are minor changes based on the characteristics of each PV where it is positioned. Each PV has unique prospective site features such as air temperature, horizon, and pollution levels, all of which influence the efficacy or value of energy produced by the floating PV. The apparent movement of the sun has a significant impact on the electricity received by the solar panel. When sunlight strikes a solar panel perpendicularly, the power density at that surface equals the power density of the light striking it. The light intensity on the surface, however, decreases as the angle between the sun and the light-absorbing surface varies. On June 22 (June solstice), the declination angle reaches a maximum of 23.45° and a minimum of -23.45° on December 21-22 (December solstice).

Figure 6 depicts the sun path of the Saguling Dam; it can be observed that the sun turns its back on the PV panels at times, such as before 07:00 in December when the sun appears with a height of 11° and after 17:00 with a height of roughly 11°. Figure 7 shows that the sun path turns its back on the PV panels at times, such as before 07:00 in December when the sun appears with a height of approximately 12°, then around 17:00 and later with a height of about 15°.

Figure 8 sun paths (height / azimuth diagram) Jatiluhur dam can be seen that there are times when the sun backs the PV panels, namely in December before 07.00 when the sun appears with a height of about 5° and after 17.00 and after with a height of about 5°.

C. Simulated Energy Production

The average simulation results of energy output generated by the floating PV system design to three dams are shown in Table 7. Saguling generates 1816.5 MWh/year of electrical energy from PV panels and distributes 1705.2 MWh/year to the grid, with an average yearly performance ratio of 0.75. The GHI of the Cirata dam floating PV system is 1799.7 kWh/m^2/year, with an average temperature of 23.09°C/year. The electrical energy generated by PV panels in this dam is expected to be 1743.3 MWh/year, and the energy provided to the grid is 1635.4 MWh per year. The annual average performance ratio is comparable to that of Saguling dam's floating PV with Jatiluhur dam. With an average temperature of 25.07°C/year, the main result of the Jatiluhur dam floating PV system has a potential GHI of 1778.9 kWh/m2/year. The PV panels generate 1719.3 MWh/year of electricity, while the energy provided to the grid is around 1611.8 MWh/year. The performance ratio of the system is 0.749. The PV tarepung saguling dam provides the most energy to the grid. Based on its potential, the most distributed energy happened in August, with 163.3 MWh, while the least energy sent to the grid occurred in January, with 119.4 MWh, for a total of 1705.2 MWh / year. Meanwhile, the PV Tarepung Cirata dam has the maximum energy supplied to the grid in July of 153.9 MWh and the lowest energy given to the system in January of 107.7 MWh, for a total of 1635.4 MWh supplied to the grid in one year.

According to Table 5, Figure 9, the floating PV system is constructed with 2176 PV panels and 544 PV panels on each inverter unit. As many as 32 PV modules can be placed in parallel, and then as many as 17 solar panels can be put in series. The PV panel circuit on inverter unit 1 is shown in this schematic; the PV panel circuits on inverter units 2, 3, and 4 are the same as the PV module inverter unit 1. This type of PV has a higher efficiency than conventional PV placed on the roof or ground. This is due to the decrease in temperature resulting from the cooling process of the water under the solar cells, when exposed to sunlight. The shading of PV panel shows that the linear loss is 0.0% and the electrical loss is 0.0%, indicating that there are no losses due to shading. The distance between module strings is made 3 m with a module length of 2.256 m, resulting in a clearance of 74.4 cm between module strings.

IV. CONCLUSION

Based on the evaluation of simulation results and modeling analysis of the design of a 1 MW grid-connected Floating-PV type solar power plant carried out at the three largest dam sites in West Java, it can be concluded that each location has the potential for floating PV development with an average amount of energy generated >1700 kWh/m2/year. Floating PV With a value of energy supplied to the grid of 1611.8 MWh / year, Jatiluhur dam has the greatest energy supplied to the system in August of 153.7 MWh and the lowest energy supplied to the grid in January of 106.9 MWh. According to table result, the floating PV at Saguling dam provides the most electricity to the grid, Cirata dam provides the second most energy, and Jatiluhur dam provides the least energy. The quantity of PV panels and string needs are modified based on standard calculations and recognized norms. Some of the solutions that support the performance of the floating PV systems of the three dams have nearly comparable values in the ratio of performance offered, so the table evaluation will need to be supported by more surveys and study.

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