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Study of The Potential for Floating Solar Power Plant in Situ Gede Bogor City

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ABSTRACT: *Floating Solar Power Plant utilized in research is located in Situ Gede Bogor City. The utilization of the situ area which has a land area of* $527290\ m^2$*. With a power plant area utilization plan of 1 Hectare the potential average solar radiation at Situ Gede is* $4{,}77\ kWh/m^2$*. The total energy generated is* $2090\ kW$*. This research uses a Interactive Microgrid as a solar power system configuration scheme. The components used are Monocrystalline solar modules with a capacity of 500 Wp totaling 4200 units, 22 inverter units with a capacity of 2458 kW, a battery unit value the total capacity is 3634,634 kW with a total of 1818 battery units, and the battery inverter capacity of 25000 W, with a total battery inverter capacity value of 8034,78 kW, which is the total use of 3 battery inverter units. The simulation results on PVSyts obtained the value of solar power plant in one year is 3148720 kWh a Performance Ratio of 84.48% and a Capacity Factor value of 17.19%. With a total initial investment cost of Rp85.033.240.352, the Payback Period is obtained in a period of 11 years with an estimated operating time of 20 years.*

KEYWORDS: *Solar Power Plant, Floating Solar Power Plant, Performance Ratio, Economic Aspect.*

I. INTRODUCTION

Day by day the need for electrical energy consumption is getting higher and higher accompanied by high pollution. Private and government efforts continue to optimize the potential of renewable energy. Solar energy is one of the abundant energy sources that has attracted attention in recent decades. One of the concepts of solar energy utilization implemented as a power plant is the Floating Solar Power Plant. Utilizing open water land (reservoirs or lakes). Bogor City has several reservoirs or lakes that have the potential for the application of Floating Solar Power Plants. In order to support the benefits of this potential, the research requires a topic that is discussed. The research will discuss the potential of a reservoir or lake to apply a Floating Solar Power Plant [1][2].

The research object is located in Situ Gede, Bogor City. It is located on the edge of a research forest owned by the Forestry Research and Development Agency. Situ Gede Kota Bogor has an area of about 6 hectares and is a daily recreation for Bogor residents. The analysis plan carried out is the application of On-Grid solar power plants (connected to the utility network or PLN network). The direction of this research is to determine the value of solar irradiation and the area to be utilized as a solar module field. If the existing conditions are known, the design and determination of floating solar power plant components can be compiled. It needs to be reviewed through the PVSyst support program in simulating the annual load. As well as analyzing the economic aspects of investing in solar power plants.

II. THEORY

Solar Power Plant is a type of power plant that is included in the renewable energy category because it does not utilize fossil fuels as its energy source. Solar power plants use sunlight as the main component in the process of producing electrical energy [3]. The Microgrid method is defined as a collection of power generation sources and loads that can operate either connected to the power grid or disconnected from the power grid. This system has solar power plants and diesel generators as sources of electrical energy, and energy storage systems in the form of batteries and local loads. Solar power plants in an interactive microgrid topology can operate in grid mode (using the power grid as a frequency and voltage reference) or in island mode (without connection to the power grid). In islanded mode, the energy storage system components, namely diesel generators, function as grid generators so that the Interactive microgrid system continues to operate and can supply microgrid loads. The interactive microgrid is also capable of black-start to support the transition of the system from grid mode to unstable islanded mode so that all generators must be turned off first [4]. The use of the floating solar system installation technique is to utilize the water surface with a floating system. This system can be installed in the sea, reservoirs, lakes, and others. Floating solar systems utilizing reservoirs or lakes have great potential because the natural evaporative cooling system from the water surface can keep the panel temperature lower. This can increase panel efficiency by up to 11% compared to ground-mounted PV systems [5].

III. METHODOLOGY

The method chosen for this research is a quantitative method because it will discuss the utilization of solar energy for a Floating Solar Power Plant in Situ Gede, Bogor City. The solar power plant system that will be used is the Interactive Microgrid method, which is defined as a combination of energy generation sources and loads that can operate connected to the utility grid and can be isolated from the utility grid [4]. This research uses secondary and primary data which is then processed using PVSyst software or relevant formulas. This research method was conducted with various approaches as follows:

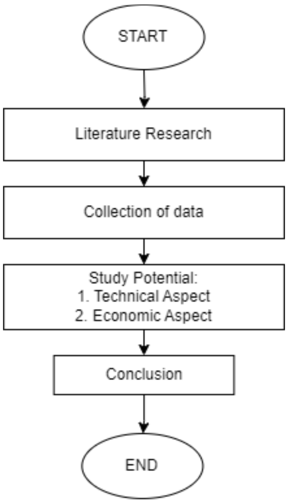

Fig 1. Research Process Diagram

IV. RESULTS AND DISCUSSION

A. FLOATING PV AREA UTILIZATION

According to the Regulation of the Minister of Public Works and Public Housing Number 7 of 2023 Article 105b paragraph 6, the provision states that if the space utilization in the reservoir inundation area for floating solar power plant is 20% [6]. As follows:

$$\text{Lpv Floating} = L_{reservoir\ Water\ Level} x 20\% \quad (1)$$

$$= 527290 m^2 x\ 20\% = 10588 m^2$$

The area marked by the red line is the total area of Situ Gede. And the area shaded by the yellow line is the area that will be utilized as a Floating Solar Power Plant space. Based on the planned utilization of the water surface area 10588 m^2 is obtained. Considering the cross-sectional arrangement of solar modules, the utilization point that will be used as the area of the Floating Solar Power Plant has an area of 10000 m^2, with a length of 100 meters and a width of 100 meters.

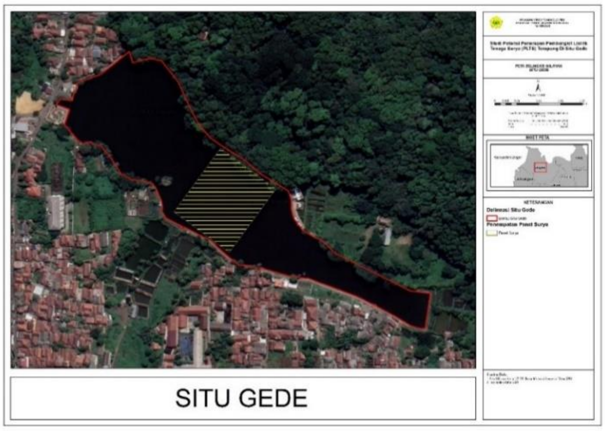

Fig 2. Area Map of Situ Gede

B. PEAK SUN HOUR (PSH)

Peak Sun Hour (PSH) or average sunshine is needed to know the average time of sunshine in 1 day [4], as follows:

$$\text{Peak Sun Hour (PSH)} = \frac{GHI}{GSTC\ x\ 365\ days} = \quad (2)$$

$$\frac{1698{,}3\ w/m^2}{1000 w/m^2 x\ 365\ days} = 4{,}77\ kWh/m^2$$

C. CAPACITY OF PHOTOVOLTAIC

The power that can be generated from all solar panels with a solar power plant utilization area of 10000 m^2 and the efficiency value of solar modules *Trina Solar* Vertek TSM-DE18M(II) is 20,9 % and the value of solar radiation intensity under STC conditions is 1000 (W/m^2) [7], can be known with the following equation:

$$P = A\ x\ \eta\ x\ GSTC \quad (3)$$

$$= 10000 M^2\ x\ 20{,}9\%\ x\ 1000\ W/m^2$$

$$= 2090000 \text{ Wp atau } 2090 \text{kWp}$$

It can be known that the power generated based on the above equation is 2090000 Wp or 2090 kWp. It can also be the amount of potential daily energy generated by the PLTS system with a PSH value of 4,77 and an area factor (System Losses) of 70% using the following equation:

$$E_{Total} = P\ x\ H\ x\ Af \quad (4)$$

$$= 2090 \text{ kW x } 4{,}77 \text{ hours x } 70\%$$

$$= 6978510 \text{ W atau } 6978{,}51 \text{ kW}$$

The total energy or power generated from the equation is 6978,51 kW. The following needs to know the value of Average Day Load (ADL) [8], with a planned loading time of 12 hours, it can be found out with the following equation:

$$ADL = \frac{Energy\ Total}{Usage\ time} \quad (5)$$

$$= \frac{6978510\ W}{12\ hours} = 581543 \text{ Wh}$$

D. INVERTER REQUIREMENT

With a large potential daily energy generated of 6978,51 kW with a PV performance ratio value of 70 %, a Peak Sun Hour value at the location of 4,77 hours, and PSH Correction 85 %. Then the capacity of the inverter can be known with the following equation:

Inverter capacity

$$= \frac{\frac{E_{Total}}{\text{Rasio Performa PV}}}{\text{PSH}} \div \text{PSH Correction} \quad (6)$$

$$= \frac{\frac{6978510\ \text{W}}{70\%}}{4{,}77\ \text{jam}} \div 85\% = \frac{9969300}{4{,}77} \div 85\%$$

$$= 2090000\ \div 85\%$$

$$= 2458824\ \text{W atau } 2458\ \text{kW}$$

Based on this equation, it can be seen that the total capacity of the inverter required by the system is 2458 kW. The number of inverters required is the result of dividing the capacity that must be met by the output power of one inverter. It can be known from the following equation:

$$N_{Inverter} = \frac{\text{Capacity inverter}}{P_{Inverter}} \quad (7)$$

$$= \frac{2458\ \text{kW}}{110\ \text{kW}} = 22{,}35 \rightarrow 22\ \text{units}$$

E. TOTAL SOLAR MODULE

The number of PV modules required is the result of dividing the PV capacity that must be met by the nominal power of one PV module (Pmax). It can be known from the following equation:

$$\text{N Solar modules} = \frac{\text{Capacity PV}}{\text{PVmax}} \quad (8)$$

$$= \frac{2090\text{kWp}}{500\ \text{Wp}}$$

$$= 4180\ \text{module} \ \rightarrow 4200\ \text{module}$$

It can be seen that the total number of solar modules based on the utilization of the area is 4200 solar module units. The number of floaters for solar modules is adjusted to the number of solar modules of 4200 solar modules, then for that, the total Float is obtained, namely 4200 float units.

F. PV CONFIGURATION

The Total PV strings and PV modules strung in series per string need to know the criteria of the PV modules and inverters used. First, create a safe and recommended range of PV modules in series per string by creating a lower limit and an upper limit of the range. Then, create a maximum string limit per inverter. The value of V_{PV-min} is 585 V, Vpv_{-start} is 250 V, Min. $V_{PV-Range}$ is 320 V, V_{mp} is 42,8 V, Max. $V_{sistem-max}$ is 1000 V, Max. V_{PV-max} is 1100 V, Max. $V_{PV-Range}$ is 460 V, V_{OC} is 51,7 V, Isc_{PV-max} is 360 V, I_{PV-max} is 234 V, I_{SC} is 12,28 V, and I_{mp} is 11,69 V [9].

A range of PV modules in series and the maximum number of PV strings per inverter was determined, namely 8 - 22 modules/string and a maximum of 20 strings/inverter. The total modules for the series per string obtained by taking the middle value of 8 - 22 modules/string is 14 modules/string. So that the required number of PV strings per inverter is met within the specified range and in accordance with the number of inputs available on the inverter, which is 9 MPPT with MPPT filled with 2 strings. So the solar PV system has 4200 PV modules and 22 inverters, with a configuration of 300 PV strings and 14 modules in series per string

G. BATTERY REQUIREMENTS

The battery capacity in this PLTS system is not functioning to be able to accommodate the total energy but enough to store excess energy from PLTS and supply during the day. Therefore, the energy that needs to be fulfilled by the battery can use the following equation:

$$\text{Battery Capacity} = \frac{E_{Total} - (ADL\ x\ 8\ hourrs)}{\eta\ Batt\ x\ DOD_{max}} \quad (9)$$

$$= \frac{6978510\ W - (581543\ W\ x\ 8\ hours)}{0{,}8\ x\ 0{,}8}$$

$$= \frac{2326166\ W}{0{,}68}$$

$$= 3634634\ \text{W atau } 3634{,}634\ \text{kW}$$

With a battery capacity value of 3634634 W and a W_{batt} value of 2 V × 1000 Ah. So that the number of batteries can be known by the following equation:

$$N_{Batt} = \frac{\text{Battery Capacity}}{W_{batt}} \quad (10)$$

$$= \frac{3634634\ W}{2\ V\ x\ 1000\ Ah}$$

$$= \frac{2334634\ W}{2000\ W}$$

$$= 1817{,}31 \rightarrow 1818\ \text{units}$$

H. INVERTER BATTERY REQUIREMENTS

The determination of battery capacity is based on dividing the maximum daily load by 125% namely 726929 W with a Power Factor value of 0,95 and multiplied by a Safety Factor value of 1,05 [10]. With the following equation:

$$\text{Inv. Batt. Capacity} = \frac{125\%\ Maximum\ day\ load\ (KW)}{\text{PF}}\ x\ (SF) \quad (11)$$

$$= \frac{726929\ W}{0{,}95}\ x\ 1{,}05$$

$$= 765188{,}42\ \text{x}\ 1{,}05$$

$$= 803478\ \text{W or } 8034{,}78\ \text{kW}$$

With a battery inverter capacity value of 803478 W d and a battery inverter capacity value of one unit of 25000 W. The total battery inverter required is the result of dividing the battery inverter capacity that must be needed (Battery Inverter Capacity) by the nominal inverter power using the following equation:

$$N_{inv-batt} = \frac{\text{Inv.Batt.Capacity}}{P_{nom}} = \frac{803478\ W}{250000\ W} = 3{,}21 \text{ or } 3 \text{ Inv.battery} \quad (12)$$

I. BATTERY CONFIGURATION

The number of parallel and parallel series of batteries must meet some criteria of the batteries and battery inverters used, i.e. the recommended range of batteries in series per parallel. With the value of Min. $V_{bat-range}$ is 500 V, P_{nom} is 250000 W, V_{bat} is 2 V, I_{max} is 361 A, Max. $V_{batt-range}$ is 820 V. It is known that the upper limit and lower limit of the battery is that the battery with a series circuit should be in the range of 250 - 410 batteries, with the battery operating voltage not close to the minimum voltage [11].

In this plan, the battery operating voltage selected is 606 V so the total battery in the series selected is 303 cells $\left(\frac{606\ V}{2\ V}\right)$. Then it is known that 1 battery bank has a capacity of $2\ V \times 1000\ Ah \times 310$ celss or equivalent to 606 kWh/bank. The number of parallel batteries required ($N_{pararel}$) is obtained by dividing the number of batteries (N_{bat}) required by the number of batteries in series. So this solar system uses 3 battery inverters, and each inverter will be connected to 2 battery banks. Therefore, 3 battery inverters, each connected to 2 battery banks containing 303 battery cells in one battery bank [4].

J. PVSYST SIMULATION

This stage involves inputting the power required in the design process by determining the type of solar panel and inverter that is suitable for the needs. The type of solar panel selected is Trina Solar Vertek TSM-DE18M(II) with a capacity of 500 Wp and a voltage of 36 V. Meanwhile, the inverter used is Sun Grow with a capacity of 110 kW and a voltage range of 200 – 850 V, with a total of 22 units used. The number of solar panels is determined based on consideration of the selected inverter, so the total number of solar panels required is 4200 units, according to the previous manual calculation [12]. The following PVsyst simulation is shown in Fig 3 below.

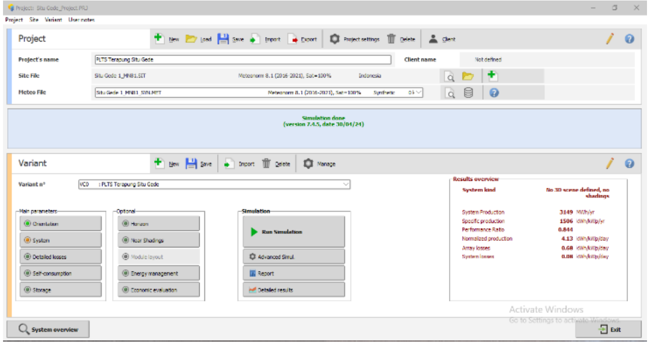

Fig 3. PVSyst Simulation

K. PERFORMANCE RATIO AND CAPACITY FACTOR ANALYSIS

After simulation from PVSyst 7.4 software, the first year energy value (EY) is 3148720 kWh/year, the Global Irradiance (GlobInc) value in 1 year is 1783,3 kWh/m^2, and the radiance in STC condition is 1 kWh/m^2, and the installed PV capacity is 2090 kW. Then it can be known with the following equation:

$$\text{PR}\ (\%) = \frac{\text{Energi Yield (1 tahun)[kWh]/Kapsitas PV}}{\text{GlobInc}/G_{stc}} \quad (13)$$

$$= \frac{3148720\ \text{kWh} \div 2090\ \text{kWh}}{1783{,}3\ \text{kWh/m}^2 \div 1\ \text{kWh/m}^2}$$

$$= \frac{1506{,}5645\ \text{kWh}}{1783{,}3\ \text{kWh/m}^2}$$

$$= 84{,}48\%$$

$$\text{CF}\ (\%) = \frac{\text{Energi Yield [kWh]}}{\text{PV Capacity} \times \text{Total hours in 1 year}} \quad (14)$$

$$= \frac{3148720\ \text{kWh}}{2090\ \text{kW} \times 8760\ \text{h}}$$

$$= \frac{3148720\ \text{kWh}}{18308{,}400\ \text{kWh}}$$

$$= 17{,}19\%$$

L. SOLAR SYSTEM INVESTMENT

The estimated initial investment cost in the Interactive Microgrid solar power plant planning that will be developed is the cost of components consisting of costs for purchasing solar panels, inverters, battery inverters, batteries, and floaters. The value of the costs incurred will greatly affect the size of the initial investment costs that will be incurred.

Tbl 1. Component Price

Component	Total Unit	Price in Dollar (USD)	Price in Rupiah (IDR)	Total
Solar Module	4200	$325	Rp 5.363.507	Rp 22.526.729.400
Inverter	22	$9600	Rp. 158.429.760	Rp 3.485.454.720
Battery	1818	$499	Rp 8.250.000	Rp 14.998.500.000

Component	Total Unit	Price in Dollar (USD)	Price in Rupiah (IDR)	Total
Inverter Battery	3	$13927	Rp 229.838.673	Rp 689.516.019
Floater	4200	$400	Rp 6.601.240	Rp 27.725.208.000
Total				Rp 69.425.408.139

With the value of the rupiah selling rate to the dollar, which is as of June 28, 2024, at Rp16.503.10. The amount of component prices is taken from online stores available in the market. The investment price used in tbl 1. does not include the cost and time of work during the Floating Solar Power Plant construction project. The initial investment cost used is for the purchase of equipment for the Floating Solar Power Plant [13].

M. OPERATIONAL AND MAINTENANCE COST

Annual operation and maintenance costs for solar power generation systems are generally calculated at 1-2% of the total initial investment cost for solar power system components [14]. This Can be known with the following equation:

$$\mathrm{OP} = 2\% \times \text{Initial investment} \quad (15)$$

$$= 2\% \times \mathrm{Rp}69.425.408.139$$

$$= \mathrm{Rp}1.388.508.162$$

N. LIFE CYCLE COST

The life cycle cost (LCC) of a solar PV system is calculated based on the present value of the total system cost of the solar PV plant, which includes the initial investment cost (C), the present value of long-term maintenance, operation, and upkeep costs (P). For example, the solar power plant to be built in this study is considered to be used for 20 years. This project life determination refers to the guarantee provided by the solar panel manufacturer. At the Bank Indonesia Board of Governors Meeting (Rapat Dewan Gubernur) on June 19-20, 2024, it was decided to maintain the Bank Indonesia lending rate at 6.25% [15]. This affects the discount rate (i). So that the operational and maintenance costs for 20 years can be known using the following equation

$$P = A\left[\frac{(1+i)^n-1}{i(1+i)^n}\right] \quad (16)$$

$$= \mathrm{Rp}1.388.508.162\left[\frac{(1+0{,}0625)^{20}}{0{,}0625(1+0{,}0625)^{20}}\right]$$

$$= \mathrm{Rp}1.388.508.162\left[\frac{2{,}3618534245}{0{,}2101158388}\right]$$

$$= \mathrm{Rp}1.388.508.162 \times 11{,}2407205377$$

$$= \mathrm{Rp}15.607.832.213$$

The results obtained from the calculation of the operational and maintenance costs of solar power plants are Rp15.607.832.213 which are used for operational and maintenance costs with an assumption for 20 years. Based on the initial investment cost (C) the Life Cycle Cost (LCC) with a PLTS life of 20 years is obtained with the following equation:

$$LCC = C + (MPW) \quad (17)$$

$$= \mathrm{Rp}69.425.408.139 + \mathrm{Rp.}\,15.607.832.213$$

$$= \mathrm{Rp}85.033.240.352$$

O. ENERGY COST OF SOLAR PV

The cost of energy is determined from the Life Cycle Cost (LCC), Capital Recovery Factor (CRF), and annual kWh production. The Cost of Energy of a solar power plant uses the following equation:

$$CRF = \frac{i(1+i)^n}{(1+i)^n-1} \quad (18)$$

$$= \frac{0{,}0625(1+0{,}0625)^{20}}{(1+0{,}0625)^{20}-1}$$

$$= \frac{0{,}2101158388}{2{,}3618534245}$$

$$= 0{,}088$$

Based on the results of the calculation of LCC, CRF, and kWh production every year, to find out the Cost of Energy (COE) with a capacity of 2090 kWp at Situ Gede Bogor City using the following equation:

$$COE = \frac{LCC \times CRF}{A\,kWh} \quad (19)$$

$$= \frac{\mathrm{Rp}85.033.240.352 \times 0{,}088}{3148720\ \mathrm{kWh}}$$

$$= \frac{\mathrm{Rp}7.482.925.150}{3148720\ \mathrm{kWh}}$$

$$= \mathrm{Rp}2.376\ /\mathrm{kWh}$$

P. PAYBACK PERIOD

With a COE value of IDR2,376 /kWh the potential energy produced by solar power plants for one year (A kWh) is 3148720 kWh, To find out the value of PLTS energy costs for one year can be known by the following equation:

$$COE\ (1\ year) = EY\ (1\ year) \times Cost(kWh) \quad (20)$$

$$= 3148720\ \mathrm{kWh} \times \mathrm{Rp}2.376\ /\mathrm{kWh}$$

$$= \mathrm{Rp}7.481.358.720$$

The total energy costs incurred during the year were Rp7.481.358.720 and the Life Cycle Cost value was Rp85.033.240.352. Then it can be known how long it takes to return the investment using the Payback Period (PP) using the following equation:

$$Payback\ Period = \frac{Life\ Cycle\ Cost}{COE\ (1\ year)} \quad (21)$$

$$= \frac{\text{Rp85.033.240.352}}{\text{Rp7.481.358.720}}$$

$$= 11\ \text{Tahun}$$

With the known Payback Period value, the initial construction of the PLTS will return in 11 years.

Q. BREAK EVEN POINT

The purpose of break-even analysis is to determine the level of activity where sales revenue is equal to the sum of all variable costs and fixed costs. If a company only has variable costs, then no break-even problem will arise in the company. The new break-even problem arises if a company in addition to having variable costs also has fixed costs. The amount of variable costs in totality will change according to changes in production volume, while the amount of fixed costs in totality does not change despite changes in production volume [16]. The following is the equation as follows:

$$Fix\ Cost = 20 - year\ operating\ costs$$

$$Fix\ Cost = \text{Rp15.607.832.213}$$

After knowing the value of the Fix Cost of Rp15.607.832.213 it is necessary to know the value of Revenue using the following equation:

$$Revenue = \frac{\Delta}{y}\ Sold\ Energy \quad (22)$$

$$= \left[\frac{\text{Rp69.425.408.139}}{\text{Rp15.607.832.213}} \times 3148720\ \text{kWh}\right] \times 11\ \text{years}$$

$$= \text{Rp154.064.501.041}$$

After knowing the value of Revenue of Rp154.064.501.041 the value of Total Cost uses the following equation:

$$Total\ Cost = \frac{B}{y}\ Sold\ energy + P \quad (23)$$

$$= \text{Rp10.857.143.731} + \text{Rp15.607.832.213}$$

$$= \text{Rp26.464.975.944}$$

V. CONCLUSION

From the technical and economic analysis of the Situ Gede Floating Solar Power Plant in Bogor City based on the calculated component specifications, the following conclusions can be drawn:

1) *The average solar energy of Situ Gede, Bogor City is* $4{,}77\ kWh/m^2$*. Based on the utilization area for the solar power plant is* $10000\ m^2$*, the PV capacity of 2 MW is obtained.*
2) *2. The solar system configuration consists of 4200 PV modules, and 2458 kW of PV inverters, with a total of 22 inverter units and a total configuration of 300 strings. Batteries with a capacity of 3634.634 kW, as many as 1818 batteries, and battery inverters with a capacity of 8034.78 kW as many as 3 units.*
3) *3. Based on simulations in PVSyts 7.4 software, the energy yield in the first year is 3148720 kWh/year, with the value of Global Irradiance (GlobInc) in 1 year which is* $1783{,}3\ kWh/m^2$*. Then the value of the Performance Ratio (PR) is* $84{,}48\%$ *and the value of the Capacity Factor (CF) is* $17{,}19\%$*.*
4) *4. Based on the results of the economic analysis calculation, the total initial investment cost is Rp85.033.240.352 based on this, the Payback Period is obtained in a period of 11 years with an estimated operating time of 20 years.*

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