Technical Study of Developing Floating Photovoltaic 145 MWac Power Plant Project In Cirata Reservoir

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Abstract. This paper is concerning how the technical study of the 145 MWac Cirata solar Floating construction was built on the cirata dam. The Cirata floating solar power plant development plan starts with the Renewable Energy Mix target set by the Indonesian government as stipulated in the National Electricity General Planning Document 2018-2037 with a target of 23% renewable energy by 2025. Technical aspects of the study are carried out on several aspects such as availability land which will determine the type of PV Land Base or floating. with some technical considerations while eventually floating technology was chosen since has technical and financial advantages for the construction of solar power plants in this location. Subsequently, an evaluation was carried out to determine the potential for irradiation at the specific location. After obtaining irradiation data and meteorological conditions, a projection of energy production in the location is carried out using the performance ratio parameters on several values to obtain the projection of annual energy production. An evaluation of interconnection was also carried out to find out whether the construction of the 145 MWac floating solar was safe against the reliability of the 150 kV and 500 kV systems in the West Java system.

1. Introduction
Based on Law no.16 of 2016 on the Ratification of the Paris Agreement, Governments of Indonesia are committed to reduce greenhouse gas emissions. For that purpose, Government of Indonesia set the target for renewable energy mix minimum 23% from energy consumption in 2025 and 32 % in 2050. This number based on target the Indonesian government's plan on electricity (RUKN) 2018-2037. The plan has been included in the Indonesian government’s plan to provide electricity compiled in the RUPTL document. Currently, renewable energy power plant installed capacity is about 8.805 MW. Which is 15% of 58 GW in term of installed capacity. As a part of government institution, PLN should contribute to this target by diversify its power plant fleet to Renewable Energy based.
| No | System   | Type | Location / Name  | Capacity (MW) | COD Target | Status       | Developer |
|----|----------|------|------------------|---------------|------------|--------------|-----------|
| 1  | Jawa Bali| PLTM | Cibuni           | 3.2           | 2020       | Funding      | IPP       |
| 2  | Jawa Bali| PLTM | Cibuni Mandiri   | 2.0           | 2020       | Funding      | IPP       |
| 3  | Jawa Bali| PLTM | Ciberang         | 1.5           | 2020       | Construction | IPP       |
| 4  | Jawa Bali| PLTM | Cikaengan -2     | 7.2           | 2020       | Funding      | IPP       |
| 5  | Jawa Bali| PLTM | Cikandang        | 6.0           | 2020       | Funding      | IPP       |
| 6  | Jawa Bali| PLTM | Kerta Mukti      | 6.3           | 2020       | Funding      | IPP       |
| 7  | Jawa Bali| PLTM | Pesantren -1     | 1.8           | 2020       | Funding      | IPP       |
| 8  | Jawa Bali| PLTS/B| Quota Spread    | 5.0           | 2020       | Planning     | Unallocated|
| 9  | Jawa Bali| PLTM | Quota Spread     | 6.5           | 2021       | Planning     | IPP       |
| 10 | Jawa Bali| PLTM | Cibanteng        | 4.2           | 2021       | Construction | IPP       |
| 11 | Jawa Bali| PLTM | Cikaengan        | 5.1           | 2021       | Construction | IPP       |
| 12 | Jawa Bali| PLTM | Cikaso – 3       | 9.9           | 2021       | Planning     | IPP       |
| 13 | Jawa Bali| PLTM | Cileunca         | 1.0           | 2021       | Construction | IPP       |
| 14 | Jawa Bali| PLTM | Cimandiri        | 4.4           | 2021       | Funding      | IPP       |
| 15 | Jawa Bali| PLTM | Cisomang         | 4.0           | 2021       | Funding      | IPP       |
| 16 | Jawa Bali| PLTM | Jayamukti        | 2.3           | 2021       | Funding      | IPP       |
| 17 | Jawa Bali| PLTS | Pareang          | 2.8           | 2021       | Funding      | IPP       |
| 18 | Jawa Bali| PLTS | Quota Spread     | 145           | 2021       | Planning     | IPP       |

Photovoltaic Solar power plant is one of the most promising technology to provide economical, clean and sustainable electricity today. Not only that, Photovoltaic power plant are ideal to rapidly increase national energy mix due to its simplicity and fast development time compared with other competing technology.

Based on sources from the RUPTL, Indonesia has a Solar energy potential of 207,898 MW (4.80 kWh / m2 / day) but currently, the installed capacity is only 78.5 MW with the utilization of 0.04%. According to the data also the potential of solar energy in Indonesia is the largest renewable energy potential when compared to the potential of Hydro energy of 75,091 MW with the utilization of 6.4%, wind energy of 60,647 MW with the utilization of 0.01%, Bioenergy of 32,654 MW with the utilization of 5.1% or from geothermal which has a potential of 29,544 MW with the utilization of 4.9%.
Following RUPTL planning, it is necessary to evaluate the plan to build a Photovoltaic Power Plant in the Cirata area which also considers development in floating or land areas. So that it can be ascertained that the construction of the Photovoltaic Power Plant is technically feasible in the planned area.

2. Data and Method

2.1. Land Availability

In addition to the Photovoltaic power plant technology that is commonly used in Ground Mounted technology, there is also floating solar technology. Seeing the geographical conditions of Indonesia which have a 54,716 km coastline with 521 natural lakes and more than 100 reservoirs, Indonesia has the potential to develop floating photovoltaics.

The planning for the use of the area chosen for the study of the floating solar power plant is the location of the cirata reservoir located in Cipeundeuy District - West Bandung Regency and Manisi District - Purwakarta Regency, West Java Province, with a location of 125 km from the Capital City of Jakarta. Following the plant development plan stated in RUPTL 2019 - 2028, PJB was assigned by PLN to carry out the development of the Cirata 145 MWac Floating Solar Power Plant (PLTS) targeted by COD in 2022. The Floating Solar Power Plant (PLTS) 145 MWac located above the Cirata dam became the first Largest Floating Solar Power Plant project in Indonesia. In the implementation of this project development assignment, PJB has conducted a process of selecting partners following the provisions in force in the PJB and declared that the MASDAR Company has been selected and approved by PLN as the shareholder of PT PJB. In Cirata reservoir there is the location of a hydroelectric power plant owned by PT PJB that is planned for Floating PV, so that the use of land to be a project in the location of the area becomes easier.

2.2. Floating PV Advantages

2.2.1. Efficiency

Commercial module Efficiency with monocrystalline modules are between 14 and 20%, and polycrystalline modules are between 12 and 17% [1]. The Floating solar photovoltaic installation opens new opportunities to increase solar power generation capacity, especially in countries with high populations limited land density and land use. Floating PV system include Conventional PV arrays as well as concentrated PV arrays that benefit from surrounding water body to prevent overheating.
condition PV module [2]. On an average efficiency of floating type solar panels are 11% higher compare to ground installed solar panel [3]. Output power depends on the solar irradiance and module temperature [4]. They has certain advantages over land-based systems, including the use of existing electricity transmissions infrastructure at the location of a hydroelectric power plant, close to demand centers (in terms of water supply reservoirs), and energy yields are increased cooling effect produced by water and reduced dust. But important to review the effects of weather conditions such as wind, water flow and floating matters such as fog that can reduce generation efficiency [5].

On the Analysis of the Potential for Use of Floating PV Power Plants on the Skadar Lake for Electricity Supply of Aluminum Plant in Montenegro found that Energy Produced in any hour can be estimated with the help of the following equation [6]:

\[ W = \bar{i} \times A \times \eta \]  

(1)

Where : \( \bar{i} \) adalah hourly Insolation, A adalah area dan \( \eta \) adalah degree of efficiency of the power plant in the analyzed hour.

The degree of efficiency of the PV power plant is determined with the following Equation

\[ \eta = \eta_{\text{module}} \times \eta_{\text{temperatur}} \times \eta_{\text{Inverter}} \]  

(2)

Where : \( \eta_{\text{module}} \) is the degree of efficiency of the module, \( \eta_{\text{temperatur}} \) is the efficiency of PV Conversion due to the influence of deflection of the PV panel temperatur from the STC value (25 °C), \( \eta_{\text{Inverter}} \) is the efficiency of the inverter.

The author [6] reduction of efficiency of the PV panel due to temperatur rise is significant and has a great influence on the reduction of PV power plant production. For silicon PV modules, a typical correlation between efficiency and temperature is 0.4 – 0.5 % / °C. It is necessary to estimate the temperatures of PV panels for the assessment of the efficiency due to a temperature rise of PV panel by using the Nominal Operating Cell Temperatur (NOCT) Method. The manufacturer determines the temperature for nominal exploitation conditions for each PV panel (NOCT—Operation Cell Temperature). By using this parameter, the temperature of a PV panel (\( T_{\text{panel}} \)) can be estimated on the basis of an ambient air temperature \( T_{\text{ambient}} \) and solar irradiance \( I \) falling onto a panel, according to the following formula [6].

\[ T_{\text{panel}} = T_{\text{ambient}} + \left( \frac{\text{NOCT} - 20^\circ}{0.8} \right) \times I \]  

(3)

Given that a typical value of the reduction of power efficiency of PV cells, due to a temperature rise of a solar cell above a standard value (25 °C), is - 0.5% / °C, the efficiency of a PV cell is calculated according to the Equation [6].

\[ \eta_{\text{temperatur}} = \eta_{\text{stc}} \times (1 - \beta \times (T_{\text{panel}} - 25^\circ)) \]  

(4)

Where \( \eta_{\text{stc}} \) is an efficiency panel on standar value 25 °C, \( \beta \) is value dependent on the material of the PV cell (0.0045 until 0.005 [6] for Crystalline silicon), \( T_{\text{ambient}} \) is an ambient temperatur, and NOCT value is majority of PV panels is about 45 °C. This condition provides more profit information in terms of efficiency due to operating temperatures in offshore PV compared to onshore PV. Better panel operating temperatures are caused by better ambient temperatures.

Two main factor considered for comparison of the efficiency of the floating PV and ground mounted PV system are the module efficiency (ME) and Efficiency Gain (EG). The efficiency of the PV module can also be calculated by [7]:

\[ \text{ME} = \frac{v_{\text{mpp}} \times i_{\text{mpp}}}{P_{\text{in}}} \times 100 \]  

(5)
Vmpp and Impp is the voltage and current of the maximum power point, Pin is the Input solar radiation. And the efficiency gain (EG) of the FPV system calculated by [7]:

$$EG = \frac{\eta_{\text{floating}} - \eta_{\text{ground}}}{\eta_{\text{ground}}} \times 100$$  \hspace{1cm} (6)

The Author [8] result study that the power at the MPP for the floating configuration is higher, even considering the disadvantages of lower irradiance value.

2.2.2. Conservation of water and Land

Another advantage of the development of floating solar power plants is by saving water and land. In its application, the floating solar power plant with 145 MW capacity will require a land area of 250 hectares. With such an area, it will reduce evaporation from water in the floating solar power plant location. Evaporation is natural phenomenon of phase change of water from liquid to vapour state [9]. The Methods to measure evaporation are: a) Pan Evaporation, b) Water Budget method, c) Mass Transfer Method and d) Energy Balance Method [10]. These conditions will directly provide water saving effect. Water saving effect this can be calculated using the formula water evaporation [11].

$$E_0 = E \times (1 - k)$$  \hspace{1cm} (7)

Where $E_0$ is the amount of water that can be prevented by the evaporation process due to being covered by a floater and $E$ is the amount of water that has evaporated under natural condition. The value of $k$ is the evaporation coefficient where this value is the ratio of the wetted area and the whole area of floater under different wind speed conditions.

2.3. Irradiation Using Meteonorm 7

Forecasting power output of the PV system can help to increase the quality of the power system. Some research are forecast the power output of PV Grid connected system without using solar radiation measurement. [12]. Some research forecasting power output need to be installed solar radiation measurement [13]. But if we need to known how the potential area will produce specific value of irradiation we can use Meteonorm Software. Meteonorm Calculation data base are referring to 10-years averages and give the maximum radiation value under clear sky conditions [14]. Meteonorm 7 is used to obtain the potential for irradiation in the Cirata PLTS project development area. The method used in the software is to determine which areas will be used as PLTS project planning. then the user can choose the calculation method on the calculation settings menu and get the desired results with the choice of results on the output format menu. the results of the calculation of meteonorm software will be seen in the result and export menus for the specific area. To conduct a solar energy system simulation, meteorological data from all parts of the world are needed. To cover many areas, the measured data can only be applied within a 50 km radius of a weather station. This makes it necessary to interpolate parameters between stations. The method given below is possible data will be interpolated and monthly values will be obtained for almost all points of the world. To calculate meteorological data for a desired location in the world, an interpolation procedure must be applied. For global radiation, this is done with the inverse 3-D distance model (Shepard gravity interpolation), based on the introduction by Zelenka et al. (1992) (IEA Task 9), with additional North-Long-distance penalties (Wald and Lefèvre, 2001), with the following calculation (2):

$$G_h(x) = \sum W_i \cdot [G_h(x_i) + (z_i - z_x) \cdot g_v] \hspace{1cm} (8)$$

$$w_i = \frac{[1 - \delta_i]/\delta_i^2]}{\sum w_k \text{ with}}$$  \hspace{1cm} (9)

$$\delta_i = \frac{d_i}{R} \text{ for } d_i < R$$
\[ w_i = \begin{cases} 0 & \text{otherwise} \\ \end{cases} \]
\[ d_i^2 = f^2_{NS} \cdot \left[ s^2 + \left( v \cdot (z_i - z_x) \right)^2 \right] \]
\[ f_{NS} = 1 + 0.3 \cdot |\varphi_i - \varphi_x| \cdot \left[ 1 + \left( \sin \varphi_i + \sin \varphi_x \right) / 2 \right] \]

Where,
\[ w_i \] : weight \( i \)
\[ w_k \] : sum of overall weights
\[ R \] : search radius (max. 2000 km)
\[ v \] : vertical scale factor
\[ s \] : horizontal (geodetic) distance [m]
\[ z_X, z_i \] : altitudes of the sites [m]
\[ i \] : Number of sites (maximum 6)
\[ \varphi_i, \varphi_x \] : altitudes of the points
\[ g_v \] : vertical gradient

After selecting the location of the Cirata Reservoir as a place for the construction of floating solar power plants then how is the study of the potential of electrical energy that can be generated in specific areas, evaluation of the location of the placement of floating solar power plants in the Cirata Reservoir in terms of the reliability of the current system in the Java Bali 500 KV system and 150 KV West Java.

To calculate performance Photovoltaic powerplant generally uses performance ratios. The performance ratio can calculate the large amount of energy that can be generated on a solar power plant and the potential for irradiation in the area. The performance ratio can be calculated using the following method

\[
\text{Performance Ratio} = \frac{\text{Actual reading of plant output in kWh p.a.}}{\text{Calculated, nominal plant output in kWh p.a.}}
\]

The calculation is for photovoltaic powerplant equipment that is already operating. Calculated nominal plant output is calculated by installed MWac capacity multiplied by Effective Sun Hour (ESH). For PLTS Planning, calculating the performance ratio can be done by using some simulation software such as Pvsys.

There are 6 subsystems in the area of West Java system that is Subsistem Bandung Selatan, Subsistem New Ujung berung, Subsistem Cirata, Subsistem Cibatu 1 – 2, Subsistem Cibatu 3 – 4, Subsistem Tasikmalaya, Subsistem Mandirancan, dan Subsistem Deltamas. There are 32 power plants in the West Java area with an average power transfer from Central Java to West Java in 2017 of 2386 MW. There are 147 locations of the 150 kV and 500 kV development plans in the West Java area with a total plan of 5,076 km, specifically in the Cirata area and also a 150kV substation expansion plan.
The total installed capacity of Net capable power in the West Java system is 8336.2 MW and 7923.5 MW. Projected electricity demand in 2019 with the assumption of economic growth of 4.83% with a projected peak load in 2019 of 7862 MW. by looking at the single line diagram, it can be seen that the 500kV network of cirata supplies the Saguling and Cibatu and Deltamas substations. By supplying the system, if later an additional 145 MW power plant is added, it will increase the supply capacity by 1.7% of the net capacity of the West Java system. The electricity load also indirectly supplies the DKI Jakarta area through the Muara Tawar Substation system.

According to the application of the operating system monitoring system of the PT PLN Persero Load Regulatory Center, the load style of the peak load of the DKI Jakarta Banten system starts at 10.00 - 12.00 and 13.00 - 14.00 WIB. The peak load of the West Java system occurred at 18:00 but the load was already relatively high at 10:00 to 16:00 or in other words the increase in load on the peak load was not too significant compared to the DKI Jakarta and Banten systems. by looking at the monitoring system application The operating arrangement of the 500 kV system in the Java Bali system also shows that there is a load transfer from the area of East Java to West Java and DKI Jakarta under normal system load conditions.

3. Result and Discussion
With the availability of land available at the existing Cirata Hydroelectric Power Plant and the ownership of the land owned, it is recommended to choose the type of floating photovoltaic. Some of the main aspects are related to land available in the Cirata hydropower area only <5 Ha. Meanwhile, the total area of the reservoir is a total of 6500 Ha. In addition, the reduction of efficiency of the PV panel due to temperature rise is significant and has a great influence on the reduction of PV power plant production. Better panel operating temperatures are caused by better ambient temperatures. Another advantage of using floating PV is minimizing the process of reducing evaporation from water in the floating solar power plant location. These conditions will directly provide a water-saving effect. This condition of saving water is also beneficial to a reservoir hydropower plant due to the indirect water-saving effect of the floating PV system is used for electricity generation hydro powerplant. However, the floating photovoltaic location must be safe against the flow towards the Cirata hydropower intake and safe from the dam inspection route. For the location of the substation, the route used to get to the existing substation is 3.2 km with 11 towers, some of which are located in the external PJB.
For meteorological conditions, the analysis is performed using the results of the simulation software meteonorm 7 with the analysis method using interpolate parameters to obtain the irradiation values and meteorological conditions needed in the specific area for the floating photovoltaic development plan. Based on meteonorm data the potential of solar irradiation in the cirata reservoir area is 4.54 kWh / m² / day.

Table 2. Meteonorm simulation result for specific location in Cirata Reservoir

| Month | H_Gh | SDm | SDb | SDastr | RR | RD | FF | DD |
|-------|------|-----|-----|--------|----|----|----|----|
| Jan   | 109  | 108 | 3.5 | 12.3   | 174| 11.0| 1.4| 270|
| Feb   | 111  | 139 | 5.0 | 12.2   | 168| 11.6| 1.4| 270|
| Mar   | 131  | 166 | 5.4 | 12.0   | 152| 12.4| 1.4| 270|
| Apr   | 125  | 143 | 4.8 | 11.8   | 102| 8.1 | 1.2| 0  |
| May   | 137  | 213 | 6.9 | 11.7   | 122| 5.7 | 1.2| 90 |
| Jun   | 138  | 228 | 7.6 | 11.6   | 73 | 4.6 | 1.2| 90 |
| Jul   | 141  | 219 | 7.1 | 11.6   | 27 | 3.6 | 1.2| 90 |
| Aug   | 157  | 259 | 8.4 | 11.8   | 19 | 2.3 | 1.2| 68 |
| Sep   | 154  | 212 | 7.1 | 12.0   | 28 | 2.1 | 1.3| 0  |
| Oct   | 147  | 191 | 6.2 | 12.1   | 112| 2.1 | 1.1| 180|
| Nov   | 153  | 198 | 6.6 | 12.3   | 219| 3.9 | 1.0| 180|
| Dec   | 123  | 116 | 3.7 | 12.4   | 225| 8.4 | 1.1| 270|
| Year  | 1624 | 2192| 6.0 | 1421   | 174| 11.0| 1.4| 270|

The energy production of the simulation results using the meteonorm software is then used to calculate the estimated energy production with a P50 probability index. The next parameter is the performance ratio (PR) comparison. This value is obtained based on the average annual PR standard for photovoltaic powerplants (80-82%) added 10% with the assumption of increased efficiency that occurs due to a decrease in module temperature under floating PV conditions. PR 88% is used for the P50 probability index. An 86% performance ratio is used for P60. An 84% performance ratio is used for P70. An 82% performance ratio is used for P80 and an 80% performance ratio is used for P90. By combining these parameters, the capacity factor value is obtained. The calculation results obtained in the P50 CF value of 16.68%. By getting this value the estimated daily energy is 696,556.80 kWh / day. Annual energy is 254,243,232 kWh / year. The specific production is 1,461.17 kWh / kWp / year and peak sun hour net is 3.99 PSH / Day.

The alternative interconnection point for allocating output power from floating photovoltaic cirata is based on several aspects, from the operation of the system, by adding on the 150 kV side will reduce IBT loading, in addition to the needs of Mvar by using a central inverter on the photovoltaic powerplant will be able to provide the Mvar supply needed by the system. By looking at the existing 500 and 150 kV subsystem cirata and considering the cost of adding new transmission towers and cables from the Cirata photovoltaic powerplant to the existing Cirata hydropower substation area, the selection of 150 kV voltage usage is better.

There are several plans for the construction of plants and transmissions in the West Java system in addition to the Cirata floating photovoltaic project to strengthen reliability and improve system efficiency including the construction of the Muara Tawar Add on block 2,3,4 with an additional capacity of 650 MW that can supply the 500 KV Cibatu Substation from 500 KV Muara Tawar, Cisokan 1040 MW Pump Storage Hydroelectric Power Plant, and several other generators. To offset the projected load growth and to strengthen the system in West Java, the additional transmission was also made with a total increase of 3128 kms by 2021 [6]. The additional 500 kV transmission area was carried out at the new Cibatu / Deltamas, Cirata and Muara Tawar transmissions, and 150 kV in the new Cibatu / Deltamas, Padalarang, Cikumpay, Purwakarta, and Cirata. By planning the addition of the power plant and transmission it can directly strengthen the West Java system, so that the influence of the 145 MW Cirata floating photovoltaic development is connected to the Cirata system in the 150
kV substation and due to Cirata floating solar power plants operate with unity power Factor (Cos φ = 0.85), then the voltage in 150 kV Cirata only slightly changed from 143.6 kV to 143.7 kV on a 150 kV system that has a voltage range of +5% and -10% according to Grid Code 2017.

The results of analysis of power flow before and after the floating PV was built and connected to the system, it appears that the loss in the average system changed from 2.6% to 2.4%. In the frequency response of the addition of floating cirata PLTS 1.7% of the total installed capacity of the power plant in the West Java system and the total Java system of 0.77% power. Effects on frequencies and voltages less than 1% can be ignored. Studies on intermittency in Cirata 1 MW PLTS changes in maximum power occur up to 2% - 5% per second. This fast lost load can be replaced by the kinetic energy of the existing power plant in the West Java system which operates using a governor free. Besides that, there are several large hydropower plants, namely Cirata 1008 MW hydropower plant, 700 MW Saguling hydropower plant, 50 MW Jatigede hydropower plant, which is still in the progress of construction and Cisokan Pump Storage Hydroelectric Power Plant, 1040 MW. the problem of intermittency is that it is expected to be minimized by the operation of the large-scale hydropower plant around the Cirata site. The addition of generating capacity will also increase hot reserves in the West Java system and transmission readiness by increasing the number and installation of IBT and other protection systems. Concerning load characteristics in the Bali Java system where under normal conditions, load transfers are carried out from Central Java to West Java so that additional generating capacity in West Java will reduce transmission losses due to power transfers.

4. Conclusions

From the above results, it is concluded that the availability of land in the area of the hydropower plant cirata for the construction of a floating solar power plant of 145 MWac is in the location of the reservoir, in the floating conditions according to the study conducted can increase the efficiency of solar power plants due to a decrease in module temperature. Besides, floating solar power plants can minimize reduce evaporation from water in the floating solar power plant location to provide benefits to existing hydro powerplant cirata. After selecting a floating location in the reservoir, a simulation is performed using meteonorm 7 to determine the potential for irradiation and meteorological data. Data from the meteonorm simulation is used to calculate the estimated energy production in that location by producing an estimated daily energy value of 696,556.80 kWh / day and annual energy of 254,243,232 kWh / year. Interconnection analysis is performed to calculate the effect of the construction of the floating solar power plant Cirata with the conclusion that the best interconnection point at a voltage of 150kV to support the reliability of the Cirata-Cibatu-Saguling subsystem. Operational reliability studies when Cirata floating solar power plants enter the West Java system are still quite safe even though they include aspects of their intermittent characteristics.

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