Study on PV System Development at UP Brantas for Hydroelectric Power Plant Station Service Supply

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Abstract. Concern toward the preservation of natural resources became one of the attention for the generation industry in Indonesia. Thus the development of renewable energy in the generation sector is important. Several hydropower plants of UP Brantas have the potential to develop PV systems in the Kolam Tando Harian (KTH) and the tailrace area. The hydropower as the object of this study, the average needed for the hydropower electricity station service per year can be calculated by calculating the PV system with 5% - 80% of the potential area that has been determined. Due to the station service costs of hydroelectric power stations increases at 0.172 $/kWH, the development of PV systems is an alternative solution to reduce the cost of hydropower station service. Refers to the capital cost of PV & energy storage issued by Lazard in 2019, it is known that the LCOE value for PV development in UP Brantas hydropower ranges between 0.11 - 0.21 $ / kWh. Compared to the import energy tariff of 0.172 $/kWH, the development of this PV plant is potential and realistic to implement. This program is aligned with government and company policies in realizing the strategic goals of renewable energy development. The development of this PV plant can be integrated later into the hydropower load center using a hybrid decentralized grid-connected PV system configuration with or without battery energy storage.

1. Introduction
PT PJB UP Brantas manages 13 hydropower plants spread over 5 districts with a total installed capacity of 291 MW consisting of annual and daily reservoir types. Kolam Tando Harian (KTH) is a term for the daily hydropower reservoir in UP Brantas. KTH has sufficient land potential for the development of floating PV has a spacious location, the intensity of solar radiation is quite good with the support of good safety factors. In general, floating PV has many advantages compared to ground-mounted PV as well as having rapid development globally [1]. The most important factor in the use of KTH as a floating location of the PV is no land investment costs, and no impact on land use so it is safe for the environment. Similar to KTH, the tailrace area of some hydropower plants also have the potential for developing floating PV or upper PV canals.

Based on the world bank's report in the floating solar market report, with the capital cost that is not much different than the ground-mounted PV [1], the development of floating PV in KTH and UP Brantas hydropower tailrace is very interesting to study its feasibility. In line with world bank reports, IRENA reports [2] as well as the results of Lazard's analysis [3] [4] it is also interesting to use as a reference to assess the feasibility of developing this PV system. Moreover, the short IESR paper on LCOE in Indonesia [5] also provides a qualitative reference in calculating the PV system LCOE at UP
Brantas. The development of PV systems in KTH and tailrace is intended to meet the needs of hydropower station service, which consists of energy needs for auxiliary services and office buildings. Based on the hydropower station service energy supply, there are 2 (two) types of hydropower station service, namely through the Auxiliary Transformer Unit (UAT) and Station Service Transformer (SST). A typical hydropower station service supply is illustrated in Figures 1a and 1b energy supply. The PV system in the red block will then supply the load center bus in parallel with the UAT or SST (hybrid). The measure of the feasibility of developing a PV system is determined by comparing the LCOE value of the PV system against the energy import tariff from the grid as a tolerable rate. For this purpose, the development of PV systems in UP Brantas Hyroelectric Power in this study is intended for hybrid grid-connected PV systems.

2. Methodology
This study was conducted using an analytical framework to determine the feasibility of implementing PV power plants in KTH and hydropower tailrace in supporting the hydropower station service energy saving program. The determination of the location of the PV system placement in the KTH and hydropower tailrace is carried out with consideration of land availability, the intensity of solar radiation, and the distance of the PV location to the power plant. Mapping the potential locations for the successful development of a PV plant in UP Brantas in Table 1.

Table 1. Potential locations for developing the Brantas PV generation

| No | Location       | Area  | Distance a (m) | Installation Type | Estimated Area (m²) |
|----|----------------|-------|----------------|-------------------|---------------------|
| 1  | Sengguruh HEPP | Tailrace | 100.00        | Floating          | 1,500.00            |
| 2  | Sutami HEPP   | Tailrace | 100.00        | Floating          | 2,500.00            |
| 3  | Wlingi HEPP   | Tailrace | 120.00        | Canal Top         | 4,200.00            |
Reservoirs and hydropower tailrace can be illustrated as shown in Figure 2.

Figure 2. Illustration of hydropower with reservoir and tailrace

The system chosen is a hybrid grid-connected PV system between PV and UAT or SST to supply the station service of hydropower. There are two considerations to determine the feasibility of implementing a PV plant in UP Brantas, namely adequate annual PV system energy output and average electricity energy cost (LCOE) below the tolerance tariff.

The annual PV system kWh fulfillment is determined based on the minimum area required by the PV system to meet the annual needs of the station service hydropower plant based on the specifications of the selected PV module. The annual electrical energy requirements for station service for each hydropower plant are shown in Table 2.

Table 2. Annual energy needs for UP Brantas hydropower station service

| No | Location     | Energy Consumption (kWH/year) |
|----|--------------|-------------------------------|
| 1  | Sengguruh HEPP | 357,229.20                   |
| 2  | Sutami HEPP  | 437,073.79                   |
| 3  | Wlingi HEPP  | 483,587.64                   |
| 4  | Lodoyo HEPP  | 256,950.24                   |
| 5  | Tulungagung HEPP | 285,279.12               |
| 6  | Mendalan HEPP | 186,858.36                   |
| 7  | Golang HEPP  | 68,370.03                    |
| 8  | Ngebel HEPP  | 33,474.20                    |
| 9  | Wonorejo HEPP | 110,635.80                   |

The average use of station service UP Brantas hydroelectric 2015-2019 (kWH)

The floating PV LCOE is calculated using the System Advisor Model (SAM) 2020.2.29 [6] [7]. Capital cost data uses a value range of 900 - 2,950 $/kW [3] for PV system. Estimation of this study uses the Floating PV Module PVM S320PD LSIS [8], with the specifications:
In this study, the degradation rate uses a value of 0.5% per year [9], the area in table 1, it is assumed that 80% will be used for PV systems (floating PV or canal top PV). Furthermore, for the districts of Malang, Blitar, Madiun, and Ponorogo, daily sun-hours in one year are assumed to be 5 hours. The development of the PV system at UP Brantas is planned to use battery energy storage or without battery energy storage. Capital cost battery energy storage uses a value range of 753 - 1,662 $/kW [4]. Furthermore, the LCOE estimation results are compared with the imported energy tariff as a reference tariff. This study is considered feasible if the estimated LCOE value is lower than the imported energy tariff. Imported energy tariffs refer to PT PLN Board of Directors Regulation No. 0283.P/DIR/2016 [10] of 2,466.78 Rp/kWH (0.172 $/kWH) [11]. The analytical framework for this study is stated in Figure 3.

![Analysis framework for PV system studies at UP Brantas](image)

**Figure 3.** Analysis framework for PV system studies at UP Brantas

Based on the company investment business process, the work plan of the PV system for each PLTA is carried out within a 1 year budget period through full equity financing.

3. Literature Review

In conjunction with the system, the PV system application is divided into [12]

- Stand-alone PV systems
- Grid-connected PV systems

3.1. Stand-alone PV systems

Is a PV system that is not connected to the network (grid). To ensure continuity of electricity supply when there is no sunlight radiation, this system is integrated with a storage system.

3.2. Grid-connected PV systems

Is a PV system that is connected to the network (grid), which is generally a connection to this network via an inverter because the PV system output is a dc voltage. This grid-connected system can be divided into [12]
Decentralized grid-connected PV systems, generally have a small capacity (<1 MW) and supply the grid through low voltage. Energy storage is not needed in this system because electricity needs when there is no solar radiation supplied from the grid.

Centralized grid-connected PV systems, generally have a large capacity (> 1 MW) and supply the grid through medium or high voltage trading.

In the journal renewable and sustainable energy review [13], in the topic of floating photovoltaic power plants explained that there are 5 (five) types of solar PV installations, namely: ground-mounted, rooftop, canal top, offshore, and floating. One of the considerations for developing solar PV is the low cost of electricity production (LCOE). LCOE is the average electricity cost that represents the minimum price an investor must receive to break even during its lifetime. The general LCOE equation is expressed as [14].

\[
LCOE = \frac{\text{Total Life Cycle Cost ($)}}{\text{Total Lifetime Energy Production (kW/Year)}}
\]  

4. Result

Based on the chosen floating PV specifications, it can be seen that the Pmax/m² solar panel PV is 165.75 Wp/m². Based on the area of the potential location chosen for the development of the PV system according to Table 1, the PV system power of each area can be calculated from the Pmax/m² multiplication results and the area. By using 80% of the area and a sun-hours period of 5 hours, the energy output per year can be calculated through equation 2 [15] and the results are shown in Table 3.

\[
\text{Energy Output} = \frac{h}{24} \times 365 \times 24 \times P
\]

| No | Location     | P estimate (kWp) | Energy Consumption (kW/year) | PV Energy (kW/year) | Surplus PV Energy (kW/year) |
|----|--------------|------------------|------------------------------|---------------------|-----------------------------|
| 1  | Sengguruh HPP | 198.90           | 357,229.20                   | 362,992.50          | 5,763.30                    |
| 2  | Sutami HPP   | 331.50           | 437,073.79                   | 604,987.50          | 167,913.71                  |
| 3  | Wlingi HPP   | 556.93           | 483,587.64                   | 1,016,397.25        | 532,809.61                  |
| 4  | Lodoyo HPP   | 265.20           | 256,950.24                   | 483,990.00          | 227,039.76                  |
| 5  | Tulungagung HPP | 384.54         | 285,279.12                   | 701,785.50          | 416,506.38                  |
| 6  | Mendalan HPP | 1829.90          | 186,858.36                   | 3,339,576.50        | 3,152,709.14                |
| 7  | Golang HPP   | 636.49           | 68,370.03                    | 1,161,594.25        | 1,093,224.22                |
| 8  | Ngebel HPP   | 129.95           | 33,474.20                    | 237,158.75          | 203,684.55                  |
| 9  | Wonorejo HPP | 251.94           | 110,635.80                   | 459,790.50          | 349,154.70                  |

When compared with the annual energy requirements according to Table 1, the energy produced from the PV power plant in the KTH and the PLTA tailrace with 80% area has been determined, each hydropower has an annual energy surplus as in Table 3. This energy surplus can be further studied which further allows the commercial development of PV systems. In this study the development of a PV system is aimed at the needs of hydropower station service, so that a minimum estimate of land requirements and the capacity of a PV generator to meet the needs of hydropower station service is shown in Table 4.
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**Table 4. Minimum land requirements and PV system capacity for hydropower station service supply**

| Location         | Area | P estimate (kWp) | PV Annual Energy (kWH) |
|------------------|------|-------------------|------------------------|
| Sengguruh HEPP   | 79%  | 1,185.00          | 196.42                 |
|                  |      |                   | 358,458.51             |
| Sutami HEPP      | 58%  | 1,450.00          | 240.34                 |
|                  |      |                   | 438,620.12             |
| Wlingi HEPP      | 39%  | 1,638.00          | 271.50                 |
|                  |      |                   | 495,489.49             |
| Lodoyo HEPP      | 43%  | 860.00            | 142.55                 |
|                  |      |                   | 260,147.10             |
| Tulungagung HEPP | 33%  | 957.00            | 158.62                 |
|                  |      |                   | 289,489.28             |
| Mendal HEPP      | 5%   | 690.00            | 114.37                 |
|                  |      |                   | 208,722.68             |
| Golang HEPP      | 5%   | 240.00            | 39.78                  |
|                  |      |                   | 72,599.19              |
| Ngebel HEPP      | 12%  | 117.60            | 19.49                  |
|                  |      |                   | 35,573.60              |
| Wonorejo HEPP    | 20%  | 380.00            | 62.99                  |
|                  |      |                   | 114,948.72             |

From Table 4 it is known that the development of a PV system in KTH and tailrace is very potential to meet the needs of hydropower station service. Using P estimate in Table 4, the LCOE PV system for PV capital cost values calculated using a range of 900 - 2,950 $/kW [3] and capital cost for battery energy storage uses a range of values of 753 - 1,662 $/kW [4]. From the results of calculations using the LCOE Calculator in the System Advisor Model (SAM) 2020.2.29 [6], then the LCOE PV system value range is obtained as shown in Table 5.

**Table 5. Land requirements and PV system capacity to supply hydropower station service**

| System               | Alternative Case | Capital Cost ($/kW) | LCOE ($/kWH) | Tarif tolerance ($/kWH) | Deviasi ($/kWH) |
|----------------------|------------------|---------------------|--------------|-------------------------|-----------------|
| PV                   | Solar PV - Crystalline Utility Scale | 900.00 | 0.05  | 0.17                  | 0.12           |
|                      | Solar PV - Crystalline Utility Scale | 1,100.00 | 0.06 | 0.17                  | 0.11           |
|                      | Solar PV - Rooftop C & I | 1,750.00 | 0.09 | 0.17                  | 0.08           |
|                      | Solar PV - Rooftop C & I | 2,950.00 | 0.14 | 0.17                  | 0.03           |
| PV + Storage         | Solar PV - Crystalline Utility Scale | 1,653.00 | 0.08 | 0.17                  | 0.09           |
| (Storage = 753 $/kW) | Solar PV - Crystalline Utility Scale | 1,853.00 | 0.09 | 0.17                  | 0.08           |
|                      | Solar PV - Rooftop C & I | 2,503.00 | 0.12 | 0.17                  | 0.05           |
|                      | Solar PV - Rooftop C & I | 3,703.00 | 0.14 | 0.17                  | 0.03           |
| PV + Storage         | Solar PV - Crystalline Utility Scale | 2,562.00 | 0.12 | 0.17                  | 0.05           |
| (Storage = 1,662 $/kW)| Solar PV - Crystalline Utility Scale | 2,762.00 | 0.13 | 0.17                  | 0.04           |
|                      | Solar PV - Rooftop C & I | 3,412.00 | 0.16 | 0.17                  | 0.01           |
|                      | Solar PV - Rooftop C & I | 3,658.00 | 0.17 | 0.17                  | 0.00           |
|                      | Solar PV - Rooftop C & I | 4,612.00 | 0.21 | 0.17                  | -0.04          |

[3] [4] Lazard analysis
[5] LCOE calculation results using the System Advisor Model
[6] Capital cost calculated to get the LCOE value of 0.17 $/kW (tolerance rate)

From the calculation results it is known that for all PV systems without storage, the PV LCOE value is lower than the tolerance tariff, while for PV systems with storage, most of the LCOE values are still below the tolerance tariff. At a capital cost above 3,658 $/kW, the LCOE value exceeds the tolerance tariff, so the magnitude of the capital cost of 3,658 $/kW is the highest capital cost that can be accepted for the implementation of a PV plant flare. This informs us that the development of a PV plant in UP Brantas to meet the needs of hydropower use alone is feasible to be implemented with 2 (two) alternatives, namely a PV system without battery energy storage and a PV system using battery energy storage with a capital cost record below 3,658 $/kW. Referring to the two alternatives, the
hybrid decentralized grid-connected system configuration is the right configuration to choose from. The grid in this study is the hydropower load center as its station service supply so that the power supply from the PV system is installed in parallel with the UAT and SST.

5. Discussion
Referring to the general picture of the major cost drivers for the development of renewable energy generation in Indonesia presented by IESR in 2019 [5], PV plants have high initial investment costs, but have small operating and maintenance variable costs (can be ignored). Investment costs consist of equipment costs, installation costs, and pre-development costs. The cost of PV equipment in Indonesia is relatively higher compared to Europe, India, and China and the global market in general. Besides, administrative and bureaucratic uncertainties also increase pre-development costs. While the installation costs due to low labor costs become an added value in the development of the PV system in UP Brantas. Considering that capital cost is the main factor that determines the value of PV generator LCOE, it is very important to observe the development of capital cost that affects the PV system LCOE in Indonesia. The capital cost used in this study [3] [4] is higher and the value range is wider when compared to the Renewable Power Generation Costs in 2019 report by IRENA [2] so that it is considered quite relevant as an analysis material for PV system development in UP Brantas.

6. Conclusion
There are two important aspects that the development of a PV plant to meet the needs of the Brantas UP hydropower station service is very potential and realistically implemented. First, UP Brantas has enough land to develop PV plants in KTH and hydropower tailrace. With the average annual electricity consumption of hydropower at this time, only a land area of 5% - 79% of the total potential land in the KTH and the PLTA tailrace is needed for the development of a PV plant. Second, using a reference capital cost PV between 900 - 3,658 $/kW, the average cost (LCOE) of developing a PV plant using both battery energy storage and without battery energy storage, in general, is still feasible to be implemented because it is still below the tolerance tariff. The development of the PV system for hydropower station service needs to provide savings in the range of 0.01 - 0.12 $/kWH. This saving is the difference between the cost of generating a PV system against imported energy tariffs as tolerance rates. For the needs of hydropower station service, the development of PV power plants is carried out using a hybrid decentralized grid-connected system configuration in the PLTA bus load center.

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