Performance evaluation of 5 MW Solar PV Power Plant in Kupang

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Abstract. Government of Indonesia have target to achieve 23% share of renewable energy in National energy mix by 2025. As a part of the target, solar energy needs to contribute as much as 6.5 GW installed capacity in 2025. Therefore, Government of Indonesia develop policy to promote renewable energy, especially solar energy. In 2013, Ministry of Energy and Mineral Resources launched High Tariff Regulation for Solar PV Power Plant. The 5 MW Kupang Solar PV Power Plant is one of the result of the policy. It was the biggest Solar PV Power Plant project in Indonesia. This project located in Oelpuah District, Kupang Regent, in East Nusa Tenggara. This Solar PV Power Plant consist of 2,208 units of 230 Wp solar PV module manufactured by state owned company namely PT. LEN Industry and 250 units of grid inverter manufactured by SMA. Started operation in March 2016, this Solar PV Power Plant already contribute in national renewable energy share. By using the recorded data, evaluation of power plant performance conduct by using Performance Ratio calculation. During March 2016 to December 2019, the Plant have produced 25.3 GWh of electricity. Based on IEC 61724 methodology, daily Performance Ratio is between 0.7 and 0.9. In additionally, economic analysis of this Plant was calculated based on realization of project income. It shows that the investment will be returned by 8th year of the Plant operation.

1. Introduction
Government of Indonesia have target to achieve 23% share of renewable energy in National energy mix by 2025 in order to promote clean and sustainable energy, and fulfil international commitment on climate change. Solar energy is one of renewable energy sources that abundant Indonesia. As a part of the target, solar energy needs to contribute as much as 6.5 GW installed capacity in 2025. Therefore, Government of Indonesia develop policy and regulation to promote renewable energy, especially solar energy. In 2013, Ministry of Energy and Mineral Resources launched Regulation that provide High Tariff for Solar PV Power Plant [1-3].

The 5 MW Kupang Solar PV Power Plant is one of the result of the regulation. The 5 MW Solar PV Power Plant in Kupang is the result of those regulation. It’s owned and developed by PT LEN Industri (Persero). This is one the state owned company. The tariff is 25 cent USD/kWh. It was the first large scale solar PV power plant in Indonesia. This power plant started operation in May 2016. It means that currently the power plant already operated more than 3 years. So, it’s a good time to do the evaluation, both of technically and economically. Accurate and consistent evaluations of PV system performance are very important to achieve production target, which leads to achievement of economical parameters [4-6].
2. Method

2.1. General information and main component specification

This Power Plant located in Oelpuah District, Kupang Regent, in East Nusa Tenggara. This Power Plant owned by PT. LEN Industry, one of State Owned Company that have business in Electronics, Communication and Solar Energy. This Solar PV Power Plant consist of 2,208 units of 230 Wp solar PV module that manufactured by PT. LEN Industry itself and 250 units of grid inverter manufactured by SMA. Based on regulation and result of bidding, the price of electricity very attractive which in 25 cent USD/kWh. Payment will be in IDR based on Jakarta Interbank Spot Dollar Rate (JISDOR) [7-10].

The Power Plant use 230P model solar panel of LENSolar. The type of solar panels is polycrystalline with dimension 1650 x 990 x 50 mm. Weight of each solar panel is 21 kg. Electrical properties of the panel are shown at table 1.

| Parameter                        | Value           |
|----------------------------------|-----------------|
| Optimum Operating Voltage       | 29.3 V          |
| Optimum Operating Current       | 7.86 A          |
| Open Circuit Voltage            | 33.2 V          |
| Short Circuit Current           | 8.31 A          |
| Maximum Power at STC            | 230 W           |
| Module Efficiency               | 14%             |
| Operating Module Temperature    | -40o C to 85o C |
| Maximum System Voltage          | 1000 VDC        |
| Maximum Series Fuse Rating      | 20 A            |
| Power Measurement Tolerance     | 0 – 3%          |

The power plant uses Sunny Tripower 2000 TLEE model manufacture by SMA Solar Technology from Germany. Electrical properties of the inverter are shown at table 2.

| Parameter                        | Value           |
|----------------------------------|-----------------|
| Input DC                         |                 |
| Max DC Power                     | 20450 W         |
| Max Input Voltage                | 1000 V          |
| MPP Voltage Range                | 580 – 800 V     |
| Max Input Current                | 36 A            |
| Output DC                        |                 |
| Rated Power (@ 230 V / 50 Hz)    | 20000 W         |
| Max Apparent AC Power            | 20000 VA        |
| Max Output Current               | 29 A            |
| Adjustment Power Factor          | 0.8 overexcited |
|                                 | 0.8 underexcited|
| Connection Phase                 | 3 Phase         |
| Efficiency                       |                 |
| Max. Efficiency                  | 98.5%           |

2.2. Performance Ratio (PR)

Performance Ratio (PR) is a globally accepted indicator to judge the performance of grid connected PV Plants. There are good examples from countries like the US, Australia and those in the European Union who have used PR as a key performance indicator to judge the performance of their PV systems. Such an analysis has helped these countries in continuously increasing the performance of their plants by rectifying system faults and thus plan for better investment decisions [11-14].
The International Electro Technical Commission (IEC) published the International standard IEC 61724 in 1998 which describes few parameters for evaluating the performance of the photovoltaic systems (Photovoltaic, 2010). PR is one of the most important measures for evaluating of a PV plant and also be used to compare PV plants supplying the grid at different locations all over the world. Performance Ratio is the ratio of Final Yield to the Reference Yield, as in

\[
PR = \frac{Final \ Yield}{Reference \ Yield}
\]

(1)

Final Yield is defined as the ratio of the annual, monthly, or daily net AC output energy of the plant to the rated DC power of the installed PV plant, as in

\[
Y_F = \frac{AC \ output \ energy}{Rated \ PV \ Power \ Plant}
\]

(2)

The rated PV plant power of this study is 5,078.4 MWp calculated from 2,708 PV modules (230Wp per module). The \( Y_F \) is widely used to compare the energy produced from PV plants differing size. Reference Yield is the ratio of total in-plane solar insulation to the PV’s reference irradiance (1000W/m² at standard test condition, STC), as in

\[
Y_R = \frac{Total \ in-plane \ Solar \ Irradiation}{Reference \ Irradiation}
\]

(3)

2.3. Performance data

Data of operations are obtained from data logger that is collected in cluster controller. For the weather and irradiance parameter, data are obtained from pyranometer. Finally, for economical aspect, data are obtained from records the meter and electricity Sales to PLN.

Energy production of the power plant represent the \( Y_F \) on performance evaluation. Data were recorded from March 2016 to December 2019. Total energy production that sold by the Power Plant to the utility are shown at table 3.

| Year | Energy Production (kWh) | Capacity Factor |
|------|--------------------------|----------------|
| 2016 | 4,700,159                | 10.73%         |
| 2017 | 6,993,331                | 15.97%         |
| 2018 | 6,328,792                | 14.45%         |
| 2019 | 7,312,691                | 16.70%         |
| Total| 25,334,972               |                |

Averaged daily energy production in one month from March 2016 to December 2019 as shown in Fig. 2. Maximum production occurred on September 2019 with 26,010 kWh/day. In some data, energy production of the power plant is recorded very low due to curtailment and system interruption or failure. The averaged energy production is 18,443.01 kWh/day. But, daily peak of production is 28,317 kWh/day which is occurred on 23rd February 2017.
Pyranometer is used to measure solar irradiation. This parameter is needed to calculate $Y_R$. Example measured solar radiation in every 5 minutes of February 23rd, 2017 as in Fig.2. The maximum solar radiation of the day is 1,023.61 W/m² between 12 AM to 1 PM.

Figure 1. Average daily energy production in one month.

Figure 2. Daily solar radiation.

2.4. Economic data
Total initial investment of the project is 120 billion Rupiah. Compared to current solar PV investment, Kupang Solar PV Power Plant is quite expensive. It is compensated by high tariff which is 25 cent USD/kWh. Based on realization of production, total income of Power Plant from March 2016 to December 2019 is about 83.9 billion Rupiah.

3. Results and discussion

3.1. Performance ratio
Performance ratio is a way to evaluate a relative efficiency of a PV system. It is calculated using equation (1). The PR of Power Plant are shown in Figure 3.
Based on the calculation, daily PR of the power plant is ranged between 0.7 and 0.9. Average of daily PR is 0.81. Based on solar irradiation data in one year, Kupang in one of the best location to develop solar PV in Indonesia.

Table 4. PR Comparison between countries.

| Location    | Performance Ratio | Reference |
|-------------|-------------------|-----------|
| Thailand    | 0.59 – 0.76       | [2]       |
| India       | 0.89              | [3]       |
| Morocco     | 0.73              | [4]       |
| Abu Dhabi   | 0.76 – 0.82       | [6]       |
| Oman        | 0.52 – 0.72       | [8]       |
| Germany     | 0.72 – 0.78       | [9]       |
| Malaysia    | 0.74 – 0.80       | [10]      |

Table 4 summarized PR measurement in some countries. Based on the PR measurement and calculation in Kupang, it shows that Kupang Solar PV Power Plant in Kupang have a good PR.

3.2. Economic and environmental analysis

Kupang Solar PV Power Plant have high initial investment but very good tariff. Table 5 collects important data to calculate financial parameters of PV project.

Table 5. Economic parameters and assumptions.

| Parameter        | Value               |
|------------------|---------------------|
| Investment       | 120 billion Rupiah  |
| Interest Rate    | 9%                  |
| Discount Factor  | 6%                  |
| O&M Cost         | 2.5% of revenue     |
| Duration of Contract | 20 years        |

Based on financial calculations, Kupang Solar PV Power Plant have a good financial parameter with project IRR 11.4, positive NPV, and 8-year Payback Period. Environmental analysis could be done by evaluate total amount of CO\textsubscript{2} emission reduction. This parameter also important because the goal of solar PV development in Indonesia is to address climate change and sustainability issue. By using emission factor of electricity system that issued by government, contribution of Kupang Solar PV Power Plant to reduce emission from March 2016 to December 2019 is 18,688 tons of CO\textsubscript{2} emission.
4. Conclusion

Kupang Solar PV Power Plant have a good Daily performance ratio which is ranged between 0.7 and 0.9. Average of daily performance ratio is 0.81. However, there are some curtailment event that need to be evaluated and discussed between PT LEN Industri and PLN. It also has good financial parameters with IRR 11.4%, positive NPV, and 8-year Payback Period. It shows that high tariff from government give positive impact to the development of solar PV power plant. As additional information, Solar PV investment at that time was still relatively high. Related to government target, the Power Plant already contribute to national target and regarding to climate change issue, the Solar PV Power Plant have reduced emission as much as 18 thousand tons of CO2 equivalent.

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