Grid Parity Analysis of Rooftop Photovoltaic in Jakarta and Surabaya

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Abstract. The growth of rooftop photovoltaic users in Indonesia has been very rapid since 2017, which around 85 percent of rooftop photovoltaic users in Indonesia are scattered in Jakarta, West Java and East Java regions. In order to deal with the trend of rooftop photovoltaic in Indonesia, the study related to the analysis of rooftop photovoltaic grid parity was carried out specifically for the Jakarta region, considering that the region includes the most rooftop users, while East Java represented by Surabaya is chosen because it has the highest solar power potential compared the two regions others. Grid Parity is the time when the electricity price equals the levelised cost of photovoltaic energy generation. To analyse the dynamics of the generation costs of a rooftop photovoltaic we use the Levelised Cost of Electricity (LCOE). To determine the average rooftop photovoltaic energy production in 2018, a model of 3 years Automatic Weather System (AWS) history data was used. For the same calculation in the next year, it is corrected by the derating factor of the system assuming a 13 percent decrease from the previous energy production each year. For the scenario of a battery-free rooftop photovoltaic system, the grid parity condition in Surabaya is expected to be achieved as early as 2021 for a capacity of 3,500 Wp and 5,500 Wp, while in Jakarta with the same capacity it will only be reached by 2022. For the scenario of a rooftop photovoltaic system with battery storage, the grid parity condition in Surabaya is expected to be achieved as early as 2024 for a capacity of 3,500 Wp, 4,400 Wp and 5,500 Wp, while in Jakarta with the same capacity it will only be reached by 2025. The Grid Parity in Surabaya is faster than in Jakarta because LCOE projections for Surabaya is cheaper than LCOE in Jakarta due to the average energy production in one year for the Surabaya region is higher than in Jakarta.

1. Introduction
Distributed generation with renewable energy is gaining much attention as it can supply
electricity directly to the nearby end users with clean energy source. Clean energy sources have increasingly-captured the attention of researchers, governments, policymakers, companies and the general public. Photovoltaic generation is a safe and mature technology, along with other renewable generations. Photovoltaic technology is probably the best type of the energy that can be achieved because it has the minimum destruction effect on the environment.

According to data on Indonesia's renewable energy potential in 2015 (see table 1), the potential of solar power in Indonesia is 207,898 MW or 50 percent of the total renewable energy potential. However, this huge potential has a small utilization of only 0.04 percent.

| Types of energy       | Potential (MW) | Installed capacity (MW) | Utilization (%) |
|-----------------------|----------------|-------------------------|-----------------|
| Geothermal energy     | 29,544         | 1,438.5                 | 4.900           |
| Water                 | 75,091         | 4,826.7                 | 6.400           |
| Mini & micro hydro    | 19,385         | 197.4                   | 1.000           |
| Bioenergy             | 32,654         | 1,671.0                 | 5.100           |
| Solar                 | 207,898        | 78.5                    | 0.040           |
| Wind                  | 60,647         | 3.1                     | 0.010           |
| Ocean energy          | 27,989         | 0.3                     | 0.002           |

The province in Indonesia which has the largest solar power potential is West Kalimantan which is equal to 20,113 MW [1-7]. Rooftop photovoltaic has now become a trend adopted by the industrial and household sectors on a small scale. In urban areas, space is limited, so placement of photovoltaic panels is usually only possible on rooftops [8]. Rooftop photovoltaic takes advantage of using abundant free urban building roofs without land occupation restriction and short construction periods [9]. With effective policies and credible solutions with available market, public demand in rooftop implementation in urban areas will naturally increase and create sustainable progress in solar rooftop industry [10]. Rooftop photovoltaic has been successfully implemented in many countries such as Germany and Japan and the USA [11].

The use of photovoltaic rooftop for household customer in Indonesia was officially allowed in 2013. The growth of rooftop photovoltaic users in Indonesia has been very rapid since 2017, where in a period of 1 year there was 118 percent growth throughout Indonesia. The rapid growth in installed capacity of rooftop photovoltaic mostly happened in big cities. Based on PLN data, in 2018 rooftop photovoltaic users are generally concentrated in Jakarta, West Java, and East Java as ‘figure 1’.
In order to deal with the trend of rooftop photovoltaic in Indonesia, the study related to the analysis of rooftop photovoltaic grid parity was carried out specifically for the Jakarta region, considering that the region includes the most rooftop users, while East Java represented by Surabaya is chosen because it has the highest solar power potential compared to the two regions others (Jakarta and West Java). This paper aims to address the question when Jakarta and Surabaya will reach grid parity. The standard definition of grid parity is the time when the electricity price equals the levelized cost of photovoltaic energy generation [12]. The term grid parity is used to indicate the symbolic milestone when a developing technology will produce electricity for the same cost of traditional technologies [13].

2. Levelized cost of electricity (LCOE) calculation

LCOE is an economic assessment of the total cost to build and operate a power-generating asset over its lifetime divided by the total energy output of the asset over that lifetime. The LCOE can also be regarded as the minimum cost at which electricity must be sold in order to achieve break-even over the lifetime of the project [14,15]. According to the International Renewable Energy Agency (IRENA), the calculation of LCOE in general is as in equation (1) [16].

\[
LCOE = \frac{\sum_{t=1}^{n} \left( \frac{I_t + M_t + F_t}{(1+r)^t} \right)}{\sum_{t=1}^{n} E_t (1+r)^t}
\]

LCOE is the average lifetime levelised cost of electricity generation (USD/kWh), \( I_t \) is investment expenditures in year \( t \) (USD), \( M_t \) is operations and maintenance expenditures in year \( t \) includes insurance costs (USD), \( F_t \) is fuel expenditure in year \( t \) (USD), \( E_t \) is electricity generation in year \( t \) (kWh), and \( r \) is discount rate and \( n \) is life of the system. Investment costs include costs for components such as solar panels (modules), inverters, batteries, solar charger controllers and installation costs. Operation and maintenance costs include cleaning and replacing small spare parts. On rooftop photovoltaic, fuel costs are
assumed to be zero.

In this paper, the LCOE calculation is carried out for Jakarta and Surabaya regions with two scenarios, consisting of a battery-free rooftop photovoltaic system and a rooftop photovoltaic system with battery storage. The installed capacity on rooftop photovoltaic varies according to household customer groups from 1,300 Wp, 2,200 Wp, 3,500 Wp, 4,400 Wp, and 5,500 Wp.

The results of calculating investment costs for battery-free rooftop photovoltaic per each installed capacity as ‘figure 2’.

![Figure 2](image)

**Figure 2.** Investment costs for battery-free rooftop photovoltaic per each installed capacity.

The results of calculating investment costs for rooftop photovoltaic with battery storage per each installed capacity as ‘figure 3’.

![Figure 3](image)

**Figure 3.** Investment costs for rooftop photovoltaic with battery storage per each installed capacity.

From ‘figure 2’ and ‘figure 3’, it can be seen that investment costs increase with increasing rooftop photovoltaic capacity.
Assumptions for operational and maintenance costs per each scenario as ‘figure 4’.

![Graph showing operational and maintenance costs per each scenario](image)

**Figure 4.** Operational and maintenance costs per each scenario.

In addition to investment costs, operational and maintenance costs, it is also necessary to calculate energy production. Energy production intended in this case is rooftop photovoltaic energy production in a one-year period. To determine the average energy of rooftop photovoltaic production, the model is used from historical data of local automatic weather stations. The average data for 3 years will be used as the basis for energy production in the first year. After using the scaling method, the output of the rooftop photovoltaic model can be determined. The result is for the same installed capacity of 1,300 Wp, it is obtained that the energy production produced by the Jakarta area reaches 2,434 kWh, the Surabaya area will amount to 2,587 kWh.

In this discussion, for a battery storage scenario, 100 percent of the production energy from the panel can be used while for the battery-free scenario, it is assumed that there is a 10 percent mismatch. In other words, it can only use 90 percent of the total photovoltaic production. For energy production in the coming years, the numbers will be different. This is because there is a derating factor from the system. The assumption for the derating factor in the photovoltaic panel as ‘figure 5’.
The value of the discount rate used is 10 percent assuming a panel life time of 20 years. With these data, LCOE analysis can be carried out for each installation capacity of 1,300 Wp, 2,200 Wp, 3,300 Wp, 4,400 Wp, and 5,500 Wp in two regions, Jakarta and Surabaya. The simulation results of the LCOE calculation if made at the net present value of 2018 can be seen as ‘figure 6’.

According to figure 6, it can be concluded that LCOE for the Surabaya region is cheaper than LCOE in Jakarta for every scenario.

3. Grid parity analysis

Grid parity analysis is to find the LCOE value that is equivalent to the existing electricity tariff. If the LCOE value is smaller or equal to the price of the electricity tariff, it can be said as a grid parity. Electricity tariffs for household customers in 2018 are equal to 1,467.28 IDR/kWh. If seen in figure 6, there is no scenario equivalent to electricity prices.
now. For this reason, forecasting is needed to determine when the grid parity will occur.
In this analysis, a projection of the components of a rooftop photovoltaic maker is carried out. To estimate module and battery prices in the coming years, curve fitting is used. Historically the module price data used is for the period from 2010 to 2017. Historically the battery price data used is for the period from 2011 to 2016. While for inverter prices and solar charger controllers, it is assumed that each year decreases with increasing installers and demand photovoltaic. The decrease in inverter prices is assumed to be 5 percent per year while the decrease in solar charger controllers is assumed to be 2.5 percent per year. Estimation of investment costs for battery-free rooftop photovoltaic per each installed capacity from 2018 to 2027 as ‘figure 7’.

**Figure 7.** Estimation of investment costs for battery-free rooftop photovoltaic per each installed capacity from 2018 to 2027.

Estimation of investment costs for rooftop photovoltaic with battery storage per each installed capacity from 2018 to 2027 as ‘figure 8’.

**Figure 8.** Estimation of investment costs for rooftop photovoltaic with battery storage per each installed capacity from 2018 to 2027.
Figure 8. Estimation of investment costs for rooftop photovoltaic with battery storage per each installed capacity in 2018-2027.

By using the investment cost assumption data mentioned above (figure 7 and figure 8), the calculation of LCOE projections from 2018 to 2027 is obtained for each region and scenario, and it can be known when grid parity will occur for rooftop photovoltaic. The calculation results of LCOE projections for the scenario of a battery-free rooftop photovoltaic in Jakarta region as ‘figure 9’ and for the scenario of a rooftop photovoltaic with battery storage in Jakarta region as ‘figure 10’.

Figure 9. LCOE projections for battery-free rooftop photovoltaic in Jakarta region for 10 years.

Figure 10. LCOE projections for rooftop photovoltaic with battery storage in Jakarta region for 10 years.

From ‘figure 9’ and ‘figure 10, it can be seen that for the scenario of a battery-free rooftop photovoltaic, the grid parity condition in Jakarta region will be achieved in 2024 for the installation capacity of 1,300 Wp, in 2023 for the capacity of 2,200 Wp and 4,400 Wp, in
2022 for the capacity of 3,500 Wp and 5,500 Wp. For the scenario of a rooftop photovoltaic with battery storage, the grid parity condition in Jakarta region will be achieved in 2026 for the installation capacity of 1,300 Wp and 2,200 Wp, in 2025 for the capacity of 3,500 Wp, 4,400 Wp and 5,500 Wp.

The calculation results of LCOE projections for the scenario of a battery-free rooftop photovoltaic in Surabaya region as ‘figure 11’ and for the scenario of a rooftop photovoltaic with battery storage in Surabaya region as ‘figure 12’.

**Figure 11.** LCOE projections for battery-free rooftop photovoltaic in Surabaya region for 10 years.

**Figure 12.** LCOE projections for rooftop photovoltaic with battery storage in Surabaya region for 10 years.

From ‘figure 11’ and ‘figure 12, it can be seen that for For the scenario of a battery-free rooftop photovoltaic, the grid parity condition in Surabaya region will be reached in 2023 for the installation capacity of 1,300 Wp, in 2022 for the capacity of 2,200 Wp, in 2021 for
the capacity of 3,500 Wp, 4,400 Wp and 5,500 Wp. For the scenario of a rooftop photovoltaic with battery storage, the grid parity condition will be reached in 2025 for the installation capacity of 1,300 Wp and 2,200 Wp, in 2024 for the capacity of 3,500 Wp, 4,400 Wp and 5,500 Wp.

4. Conclusion
In this study, we have analyzed grid parity conditions for the Jakarta and Surabaya regions with two scenarios, consisting of a battery-free rooftop photovoltaic system and a rooftop photovoltaic system with battery storage. Evaluation of grid parity shows that the grid parity with rooftop photovoltaic systems is impossible with the current cost in 2018. From our grid parity analysis, for the scenario of a battery-free rooftop photovoltaic system, the grid parity condition in Surabaya is expected to be achieved as early as 2021 for a capacity of 3,500 Wp and 5,500 Wp, while in Jakarta with the same capacity it will only be reached by 2022. For the scenario of a rooftop photovoltaic system with battery storage, the grid parity condition in Surabaya is expected to be achieved as early as 2024 for a capacity of 3,500 Wp, 4,400 Wp and 5,500 Wp, while in Jakarta with the same capacity it will only be reached by 2025. The Grid Parity in Surabaya is faster than in Jakarta because LCOE projections for Surabaya is cheaper than LCOE in Jakarta due to the average energy production in one year for the Surabaya region is higher than in Jakarta.

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