An academic review on the performance of the Sidrap wind turbine, Sulawesi – Indonesia

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Abstract. To secure the energy availability in Indonesia, the Government of Indonesia has tried to find new contributions from the renewable energy resources, one of them is the wind energy. In 2018, a new wind farm in Sidrap, Sulawesi, started to operate and was expected to generate 75 MW electricity from 30 wind turbines in the farm. However, the performance of this wind farm has been criticized by some popular figures in Indonesia, including the Minister of Finance of Indonesia who mentioned its performance as under expectation. On the other side, the Indonesian National Electricity Company (PLN) has reported some data on mass media indicating that this wind farm is producing as expected. To understand the critics, an academic review based on the standard knowledge in wind energy theory has been done. The study includes the review of wind speed in Sidrap, the maximum expected power from the wind turbines, and some other evaluations. It is expected that the critics can be understood in a fair way and be a lesson learned for the future wind farm development in Indonesia.

1. Introduction
In April 2018, a new wind farm started to operate in Sidrap, Sulawesi, as part of the Indonesian government plan to secure the domestic energy availability. The Sidrap wind farm (PLTB Sidrap) was established to provide 75 MW electricity from 30 wind turbines distributed in the farm. The wind farm will provide electricity for 70,000 home consumers in South Sulawesi. Claimed to be the first wind farm in Indonesia and the biggest one in South East Asia, PLTB Sidrap received critics from public figures concerning its performance. The Finance Minister, for example, has openly criticized the wind farm as “enough for making presentation”. An ex-minister, also a senior writer, has warned the production uncertainty due to the uncertainty in having enough wind to operate the turbines.

On the other side, some mass media have reported that this wind farm is producing as expected and is beyond the projection. The wind farm has been able to produce 400,000 MWh in two years. However, it has been observed that the operation of the wind farm varies by seasons in Indonesia. Higher production is recorded between April and October when stronger wind blows, and the production decreases between November and March when weaker wind blows.

To understand the critics, an academic review based on the standard knowledge in wind energy theory has been done. The study includes the review of wind speed in Sidrap, the maximum expected power from the wind turbines, and some other simple calculations. It is expected that the critics can be understood in a fair way and be a lesson learned for the future wind farm development in Indonesia.

This study is mainly a literature study with some practical calculation based on the technical data of the airfoil used in Sidrap wind farm. In the author’s observation, though it is a simple approach, this
basic methodology has not been used in predicting the power that we can produce from a wind farm in Indonesia.

2. Methods
This study was mainly based on the Blade Element Momentum theory as, for example, given by Kedare [1]. Some basic formulas that were used to analyze the performance of Sidrap wind turbine are described below.

2.1. Power in wind
The theoretical output power (or power in wind) that can be generated from a wind blade is defined as a blade element momentum equation described in the following equation:

\[ P_w = 0.5 \rho A v^3 \]

where \( P_w \) is the power in wind (in Watt), \( \rho \) is air density (in kg/m\(^3\)), \( A \) is the area covered by the blade rotation (in m\(^2\)), and \( v \) is wind speed (in m/s). The area \( A \) simply equals to \( \pi l^2 \) where \( l \) is the length of the wind blade. The formula suggests that the power in wind is strongly determined by the wind speed \( v \). Therefore, to obtain high output power wind turbine, it is recommended that the wind turbine should be built in strong wind area.

2.2. Betz limit
Betz limit is a theoretical limit representing the maximum power or power coefficient that can be extracted from a wind rotor and is defined as \( C_{P,\text{max}} \), the maximum power coefficient, which is equals to 0.59. The equation indicates that given a power in wind value of 1 Mw, for example, the maximum power that can be extracted from a wind blade is only 0.59 Mw or 590 Kw. The Betz limit suggests that a wind turbine development plan needs to include this formula to understand the limit of the power that can be produced ideally. The actual power that can be produced may be less than Betz limit.

2.3. Lift and drag
The first two factors mentioned above are factors that contribute to the estimation of the expected power without thinking about technical design of the airfoil used to construct the wind turbine. In practice, a wind blade has aerodynamics consideration. The shape of the blade will affect the lift and drag forces which in turn affects the performance of the wind turbine and hence, the generated power. However, due to the lack of information on the type of the airfoil used in Sidrap wind farm, the author decided to exclude the analysis of the expected power from this study and will focus only at the “frictionless” power calculation.

3. Results and discussions

3.1. Location
Sidrap wind farm (PLTB Sidrap) is an operational onshore wind farm located in South Sulawesi, Indonesia. The wind farm has a latitude of -3° 59’ 14.3” and longitude of 119° 42’ 41.3” on WGS84 geodetic system. It was built on mountainous area extending from the north to the south of the South Sulawesi province (Figure 1).
3.2. Technical data
The PLTB Sidrap was commissioned in 2018 and uses Gamesa G114 2.625 MW turbine that can produce the targeted power of 2.5 MW. The radius of the rotor is 57 m with the hub height of 80 m. Having 30 operational turbines, the wind farm is expected to generate a total nominal power of 75 MW.

3.3. Wind speed
The next information needed to accomplish this study is the wind speed in Sidrap area. The wind speed map of the area is shown in Figure 2 [2]. The map clearly shows that the wind speed around Sidrap area is between 7.0 – 7.5 m/s at 100 meter elevation. The average wind speed at Sidrap area for several years since 2004 until 2015 has been also reported by a local research as shown by Figure 3 [3]. The report indicates that the average wind speed is in the range of 5.0 – 7.5 m/s. It is observed that strong wind happens in the months of April until October, while lower wind speed happens during November to March. In addition, during the feasibility study done by the developer at 14 different wind observation stations in the area using direct observation and remote sensing, the average wind speed varies from 5.2 m/s to 10.6 m/s (UPC Renewables Project Report) and by a simple averaging an average wind speed of 7.7 m/s can be determined for the area. It is important to know that the technical specification of the turbine suggests that the electricity can be generated at the minimum wind speed of 3 m/s. Looking at the Weibull distribution of the wind speed in the area which include the wind speed between 0 to 3 m/s, there may be some times when the turbines stop to operate and don’t produce electricity due to this low wind speed.
Figure 2. The wind speed map around PLTB Sidrap. The map clearly shows that the wind speed around Sidrap area is between 7.0 – 7.5 m/s at 100 meter elevation.

Figure 3. The wind speed at Sidrap area from the year of 2004 to 2015. The report indicates that the average wind speed is in the range of 5.0 – 7.5 m/s.

3.4. Actual production
The recorded production in 2 years since the wind farm started to operate is 400,000 MWh or 200,000 MWh in one year. No detailed records from the PLN (National Electricity Company) are available during this study.

3.5. Analysis and result
Based on the technical data, some calculation results will be now discussed. Knowing that the radius of the wind blade is 57 m, the average wind speed in the area is assumed to be 7.7 m/s, and the density of the air is assumed to be 1.225 kg/m$^3$, the power in wind can be calculated and a value of 2.85 MW is obtained. This value is higher than 2.5 MW which is the expected power from a single turbine.

As the maximum power is determined by Betz limit, the nominal power is multiplied by the Betz coefficient (0.59) to yield a maximum power of 1.68 MW. To get the total maximum power from 30 turbines, this number is multiplied by 30 to obtain 50.52 MW daily production, lower than the expected daily production of 75 MW. By assuming that the wind turbines operate 24 hours a day along the year, we obtain annual production around 442,000 MWh, or two years production of 884,000 MWh. This number is doubled compared to the recorded watt-hours which is 400,000 MWh.
The explanation of why the actual production is less than the theoretical estimation can come from several reasons:

- The power coefficient, or the efficiency, is lower than the Betz limit, which is an acceptable cause. By doing simple calculation, a power coefficient of 0.26-0.27 can match the actual annual production.
- The wind speed varies from one place to another place and can be lower at certain condition. It has been explained earlier that between November and March the wind speed is lower due to the raining season.
- It could be that some turbines stop their production during low wind speed and therefore reduces the hours or days of production. The turbine technical specification shows that it can still work at wind speed of 10.6 m/s or higher and therefore should not be an issue at high wind speed.

As mentioned earlier, the approach used in this study will yield a maximum output power that is higher than the actual generated power. To achieve better output power estimation, which is useful for future power estimation of wind farms in Indonesia, more advanced analysis can be done by incorporating numerical modelling that predicts the output power as function of several variables such as: blade design parameters [4-7], wake [8-10], terrain [11,12], and any other physical variables. New developments on numerical simulation have also made the prediction of future output power for energy management possible by using the artificial neural network [13,14]. The condition of wind turbine can be also monitored by using the now-popular machine learning method [15].

4. Conclusions

Based on the simple approach in this study, it is obvious that the existing electricity production of the PLTB Sidrap is still acceptable from the theoretical view. The critics on the PLTB Sidrap performance is probably caused by lack of understanding of the technical terminology of wind turbines.

However, due to the limited information collected during this study, it is recommended that a further and deeper study is done to get a better understanding in the performance of PLTB Sidrap by filling the information gap that exists in this study. The information may include PLTB Sidrap daily production data, detailed wind speed data (speed and direction), complete technical specification of the wind turbine including rated power that can be gained, and other information needed to do a better analysis.

In addition, to do a more accurate analysis, an LLT simulation [16] can be done to predict the wind turbine output power during operation. Therefore, a detailed information on the airfoil shape is also needed. In future, advanced numerical analysis such as machine learning or deep learning can be used to predict the wind behavior in Sidrap area and then used to predict the PLTB Sidrap output power for its electricity distribution planning and management.

References

[1] Kedare S B 2008 Wind Energy Conversion Systems (Lecture Notes)
[2] http://globalwindatlas.info/area/indonesia/
[3] http://indonesia.windprospecting.com/
[4] Alaskari M, Abdullah O and Majeed M H 2019 Analysis of wind turbine using QBlade software IOP conference series: materials science and engineering 518(3) 032020
[5] Júnior C J F, Cardozo A C P, Júnior V M and Neto A G 2019 Modeling wind turbine blades by geometrically-exact beam and shell elements: A comparative approach Engineering Structures 180 357-378
[6] Memon A, Samo S R, Asad M and Mangi F H 2015 Modeling of aerodynamics forces on the wind turbine blades Journal of Clean Energy Technologies 3 406
[7] Baumgart A 2002 A mathematical model for wind turbine blades Journal of sound and vibration 251(1) 1-12
[8] Neiva A, Guedes V, Massa C and de Freitas D 2019 A review of wind turbine wake models for microscale wind park simulation Proceedings of 25th ABCM International Congress of
Mechanical Engineering

[9] Troldborg N, Sorensen J N and Mikkelsen R 2010 Numerical simulations of wake characteristics of a wind turbine in uniform inflow Wind Energy: An International Journal for Progress and Applications in Wind Power Conversion Technology 13(1) 86-99

[10] Schmidt J and Stoevesandt B 2015 The impact of wake models on wind farm layout optimization Journal of Physics: Conference Series 625(1) 012040

[11] Prospathopoulos J M, Politis E S and Chaviaropoulos P K 2008 Modelling wind turbine wakes in complex terrain Proceedings EWEC 2008, Brussels, Belgium

[12] Bechmann A and Sørensen N N 2010 Hybrid RANS/LES method for wind flow over complex terrain Wind Energy: An International Journal for Progress and Applications in Wind Power Conversion Technology 13(1) 36-50

[13] Marugán A P, Márquez F P G, Perez J M P and Ruiz-Hernández D 2018 A survey of artificial neural network in wind energy systems Applied energy 228 1822-1836

[14] Singh S, Bhatti T S and Kothari D P 2007 Wind power estimation using artificial neural network Journal of Energy Engineering 133(1) 46-52

[15] Stetco A, Dinmohammadi F, Zhao X, Robu V, Flynn D, Barnes M, ... and Nenadic G 2019 Machine learning methods for wind turbine condition monitoring: A review Renewable energy 133 620-635

[16] Marten D, Lennie M, Pechlivanoglou G, Nayeri C N and Paschereit C O 2016 Implementation, optimization, and validation of a nonlinear lifting line-free vortex wake module within the wind turbine simulation code qblade Journal of Engineering for Gas Turbines and Power 138(7)