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Analysis of wind energy potential and wind energy development to evaluate performance of wind turbine installation in Bali, Indonesia

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ABSTRACT

In recent years, Wind power generation in Indonesia is no longer a new issue. Indonesia has average velocity from 2 m/s to 7 m/s. Based on the monitoring data from meteorological, climatological, and geophysical agency (BMKG), the average wind velocity in Bali is 2 m/s – 5 m/s, hence Bali has potential to development and utilization the source for wind turbine installation, There are four stations of BMKG in Bali, which each station is supervise the region. Weibull distribution has been represented on this research to calculate and determine the probability of the each of region to know the availibility of the source with some correlation. i.e. probability density function and cumulative distribution function with both of them describes the probability that an event occurs at time and the probability that an individual survives until time. Literally, Jembrana station has the lowest availability of power available from the district and cities in Bali, compared with districts and cities in Bali, and also the KHK station has the highest probability of wind power than the other regions.

Keywords: Energy sustainability; wind energy; wind turbine; wind average probability; wind power density.

INTRODUCTION

The wind farm production depends on meteorological conditions, especially the importance of the wind speed and also can't be precisely affected by human interference. Thus, in wind energy systems, freestream air plays the most curcial role when the energy generated by the wind energy conversion system is evaluated. Indonesia has an average velocity from 2 m/s to 7 m/s. With that characteristic it, Indonesia is suitable small and medium wind power (10kW). In Bali, the average velocity range from 2-4 m/s, which the speed annual average should be at least 3.65 m/s at 50 m [1].

Wind turbines, as energy conversion facilities into the most widely used electrical energy, can be one of the answers to the energy crisis problem. Because Bali island has an expanding requirement for electricity power with lack of increased inventory power and also in the site of planning and construction of wind turbines, the probability distribution of wind speed becomes very curcial in determining the energy output. Wind speed distribution has been explored by several scientists with two major parameters Weibull and Rayleigh distribution are often quoted as famous distribution for wind speed probability.

However, some researchers have indicated that the Weibull and Rayleigh distribution should be used in a determining the probability of the wind speed. The earliest research from Hardianto et al. [2] shows the promising of wind energy and arrangmenent wind turbine design on Jember, East java, Indonesia, it present that the data was analyzed with statistical linear function of a representative wind speed, taken to average of the wind speed and also it be used as mention for the development of wind turbine with a durable systems. The representative wind speed modeled as having a Weibull distribution with parameters chosen so as to show agreement with its estimated mean and variance The wind share factor is the part of the important rule to estimate the power of wind turbine construction. The previous research Qing et al. [3] was present that a Weibull and Reyleigh function of wind ramps also given to estimate the energy capacity requirement of the energy storage systems. The other research from Liu et al. [4] describes the Weibull function is a great exemplary that matches the monthly of probability density distribution. Meanwhile, the Weibull model also demonstrate with great electricity estimates if using for a annual. The paper from Hossieni et al. [5] shows using characteristics of Weibull fucntion gives the new turbine model based on the determination of capacity and availability factor from the wind source and the research from the other country from Kodapani et al. [6] explain that Weibull distribution great compatible with the explored characteristic of wind speed distribution in the India.

In the following, we first motivate our model with references to widely used statistical linear function with Weibull distribution for wind speed probability in Bali, Indonesia. The file used in this research be composed of second wind speed (m/s) from four stations across the island. The collection period was from January 2012 to January 2016. Data were obtained from the meteorological, climatological, and geophysical agency (BMKG). This paper organizes as follows. Section two describes the sites and study of potential energy, section three provides the methodology and assessment of the case with two installations that have been operating in Bali and also the solver of probability of wind speed and wind density power, section four presents the result and statistical analysis of probability and the other variable that depends on each other with the wind turbine rule, section five presents the conclusion of this paper.

In this research, the opportunity of employing a small wind turbines in Bali to harvest wind source is inspected theoretically and by simulation using Q-blade for the design and Weibull distribution through finding the probability of the wind speed, maximum power produced based on the probability, and the availability of the wind energy each of region in Bali. In the last decade, some investigator studied the wind power potential of some sites and it's wind characteristics in desert regions of Bali island and has been achieved with a few articles [3], [7], [8]–[18]. The objective is to mapping wind energy potential in the region of Bali and to determine the source of wind energy to possibility install the small wind turbines.

MATERIALS AND METHODS

Wind energy sources are performed that one may predict the promising of wind energy in the area. It requires the wind turbine climate secondary data for mesoscale and primary data for the micro scale that found from meteorological, climatological, and Geophysical stations (BMKG). The first task when calculating the potential of wind resource and assessment of power curve performance is to confirm the geographical appearances of the field, that field must be considered as a complex field [19]. It can be seen that the potential resource at the first time can calculate the average velocity for base data from all area in Bali and also the second task also calculates the probability of distribution average velocity and specific power each of area according to the probability of wind resource. SuiTabledistribution foe each wind station were determined by the Weibull distribution that the correlation based on the previous research from [7].

Primary Data

Primary data includes wind characteristics throughout Bali, which includes four BMKG stations (Ngurah Rai, Sanglah, Jembrana, and KHK), the ie direction of velocity, pressure, temperature, and velocity from 2012-2016. Data is presented on average per month for 5 years. The variable is velocity, temperature, and pressure. For example, Table1 shows the average data that obtained from four BMKG stations in Bali that has been calculated based on the many data that received on BMKG.

Table 1. Wind Characteristics at Bali (2012-2016).

BMKG Stations	Years	Pressure (Kpa)	Temperature (K)	Average velocity (m/s)
Sanglah	2012-2016	97.55992	298,5	3.31
Ngurah Rai	2012-2016	100.9723	299.1	3.186673565
Jembrana	2012-2016	101.1081	299.4	1.284733159
KHK	2012-2016	101.0788	299.37	3.532921021

Table 1 shows, the characters from each of BMKG station in Bali. Jembrana station has the lowest average velocity than the other station in Bali, and KHK station has the highest average velocity than the other station. It can be known as the probability velocity of this place to give the parameter wind turbine design.

Distribution of Wind Relative and Wind Cumulative

A frequency value from mean velocity can be calculated and analyzed using the relative and cumulative distribution function. The distribution function used are Weibull Probability [2]. The Previous research [5] has explain that the Weibull distribution function has benefits in the assessment of wind potential resources because of its adaptability and simplicity, but has mainly been found to adapt various collections of wind record data sources. When the wind speed frequency for a site is unknown then the Weibull distribution can be used to estimate the velocity distribution for a site by putting in the geometry parameter and scale parameter. It can be seen as follows;

Weibull distribution:

$$f(v) = \frac{k}{C}.\left(\frac{v}{C}\right)^{k-1} \exp\left[-\left(\frac{v}{C}\right)^{k}\right] \tag{1}$$

Where V is the wind speed (m/s) and k and C are the parameters specified from the data. According to the cumulative functions the probability of Weibull distribution has represented the feasibility for the wind speed lower than a particular number of V_0 [8].

$$F\ (v \leq v_0) = 1 - \exp\left[-\left(\frac{v}{C}\right)^k\right] \tag{2}$$

Equation from (2) can be decribes as follows

$$\ln\big(-\ln\big(1 - F(v \leq v_0)\big)\big) = k\ ln\left(\frac{v_0}{C}\right) = k \ln v_0 - k \ln C \tag{3}$$

The variables of the two important parameters, *K* and *C* can be determined by the smallest squares from data source, as folllows

$$Y = A + B.X \tag{4}$$

where,

$$Y = \ln(-\ln\big(1 - F(v \leq v_0)\big)) \tag{5}$$

and the value of *X* can be calculated as follows,

$$X = \ln v_0 \tag{6}$$

Unfortunately, multivariate extensions of the Weibull [2] appear to be quit interacTablefor purpose of modeling multiple site wind speed distribution. Therefore, exploit the fact that simple power transformation of Weibull distributed random variables can have distribution very closely approximating the normal, for which a multivariate extension is readily available. The potential value of wind energy can be determined by the following equation.

There are several factors in methodology and variables that affect the performance and construction of wind turbine installations, both based on data collection, calculation of potential power generated, effects of wind shear and topography of the area along with velocity probability calculations [20].

Impact of Tower Height

The friction of the moving air masses against the earth surface slows down the wind speed from undisturbed value at good altitude to zero directly at ground level, where each location or location of the topography has a different friction coefficient [21]. The velocity will raise with the height because the friction at earth surface is large. The rate of the rate of increase of wind speed that is often used to characterize the impact of the roughness of the earth surface, it is given as :

$$\left[\frac{V}{V_O}\right] = \left[\frac{H}{H_O}\right]^{\propto} \tag{7}$$

where $V$is the wind spped at height *H*, v_o is normal wind speed at height H_o, and α is the friction coefficient. This can be translated into a substantial increase in a power at greater heights, the power law provides a reasonable first approximation to the change of the wind speed with height under most meteorological conditions. If data on surface roughness and atmospheric stability were available, a better approximation could be achieved using the log wind profile.

Table 2. Friction coefficient on characteristic area [22].

Terrain characteristics	Friction coefficient
Smooth hard ground, calm water	0.10
Tall grass on ground	0.15
WoodeTall grass on ground	0.20
High crops and hedges country side, many trees	0.25
Small area with many trees	0.30
Large area with height constructions and industry area	0.35

Some extending information is requires, such as windrose, wind direction, topography, roughness.

Energy Evaluation and Wind Power Density Calculation

To analyze the wind-based energy production, the distribution of the energy produced by a wind turbine differs in wind speed per unit time and rotor area, which is called the power density distribution *e(v)* in W/m^2 [11] and is explained as :

$$e(v) = \frac{1}{A} f(v) p(v) \tag{8}$$

By considering the equation , the follwing equation can be calculated as below:

$$e(v) = \frac{1}{2}\rho C_{p,eq} \begin{cases} 0\ v < v_{ci} or\ v > v_{\infty} \\ v^3 f(v) v_{ci} \leq v \leq v_r \\ v_r^3 f(v) v_r < v \leq v_{\infty} \end{cases} \tag{9}$$

The total power density *E* at a specific wind site can be calculated as below:

$$E = \int_{v_{ci}}^{v_{co}} e(v) dv = \frac{1}{2}\rho C_{p,eq} \left(\int_{v_{ci}}^{v_r} V^3 f(dv) + \int_{v_r}^{v_{co}} v_r^3 f(v) dv \right) \tag{10}$$

as a special case, a power density of *E* can be received analytic which the wind is showed by a Weibull probability distribution function [23]–[26]. The case can be determined as follows

$$P(v) = \frac{1}{2} p v^2 \tag{11}$$

Based on the equation on the determined wind probability density, we can determine the measured wind power density from the Equation [15] as follows.

$$P_{m,R} = \sum_{j=1}^{n} \left[\frac{1}{2} p v_{m,j}^{3} f(v_j)\right] \tag{12}$$

If *f(v)* is the Weibull probability allocation of *v*, the average power density for the Weibull function can be calculated as follows [4].

$$P_W = \frac{1}{2}\rho . c^3 \Gamma \left[1 + \frac{3}{k}\right] \tag{13}$$

where Γ is gamma function and ρ is air density. Air density can be calculated from the mean temperature and pressure each of region in Bali. It can be estimated that wind power density immediately be convinced on Weibull parameters.

RESULTS AND DISCUSSION

The concerns of statistical studies from wind characteristic and wind power density in Bali island are showed. The characteristics were formed using Weibull equation and estimated parameters. It was present that the Weibull function with the estimated parameters of this approach predicts seasonal variations in the average wind speed and the strength of each density more accurately than the normal approach. The data used in this study consists of secondly wind speed (m/s) from four BMKG stations across the island i.e. Sanglah station, Ngurah Rai station, Jembrana station, and KHK station.

The collection period was from January 2012 to January 2016. Data were obtained from the meteorological, climatological, and geophysical agency (BMKG). The primary data were finding i.e. the direction of the wind, wind speed, temperature, and pressure. The wind speed average has been determined based on the basic data from four stations and also based on it. Basically The Weibull function are used to descibe the wind speed distribution of a given during a certain period of times, usually a hour, a day, even in a year. In the present study, the seasonal Weibull distribution function and two parameters derived from the data collected. At present, The Weibull equation is used to analyze the wind speed average probability each of station to justify the potential area to developed wind energy in Bali.

There is three graphs that represented the wind energy source in Bali according to the data from four BMKG stations. Based on the recalculation about the wind source potential in Bali, we can giving a assessment and repairs to reconstrcuction the wind turbine that had been installation in Bali, because during the operation, the prototypes of wind turbine giving a beyond expectations on performance of this cases from the missing construction between wind source and the design of the wind turbine.

Wind Speed Probability and Wind Density Power in Bali

Bali island has a potential wind energy resource from the location of Indonesia. Based on calculation the source of wind energy at Bali. The raw data set (5475 points) contains some invalid data points which should be filtered for further statistical analysis. An initial preliminary data pre-processing was performed on days data form annually. The distribution of velocity probability each of region has been calculated with Weibull distribution, there are four meteorological, climatological, and Geophysical stations (BMKG) that supervise each district in Bali i.e. Sanglah station, Ngurah Rai station, Jembrana station, and KHK stations. The Weibull allocation is applied to shows the wind speed characteristic because of its simplicity to estimate the mean and standard deviation of the total power density and its ability to assume the characteristic of many different types of distribution, however as reviewed in the introduction section, this analysis shown two main parameter Weibull distribution that explain a great fit to wind data evaluating the wind source potential in Bali. Moreover a two component mixture the Weibull distribution has the ability to represent heterogenous wind regimes. And those data and result of the Weibull probability function will explain as below.

Table 3. The Stastistical result of the average wind speed data in four BMKG stations (2012-2016).

Wind speed (m/s)	Average wind Speed Probability in Sanglah	Average wind Speed Probability in Ngurah Rai	Average wind Speed Probability in Jembrana	Average wind Speed Probability in KHK
0	0	0	0	0
1	0.16686	0.17848	0.66112	0.1479
2	0.25367	0.26565	0.21475	0.2326
3	0.24091	0.24354	0.01557	0.23374
4	0.16939	0.16298	2.98882E-4	0.17787
5	0	0	0	0.15842
6	0	0	0	0.19011

The Weibull distribution is represented to determine the data from BMKG, Table 3 shows the average wind speed probability in four BMKG stations, which their stations is represented that the average wind speed in Bali has a potential resources to develop the small wind turbine because an example, at KHK station, has the high probability with range 0.15842-0.19011 at 5-6 m/s at an altitude of 0 m below the sea surface.

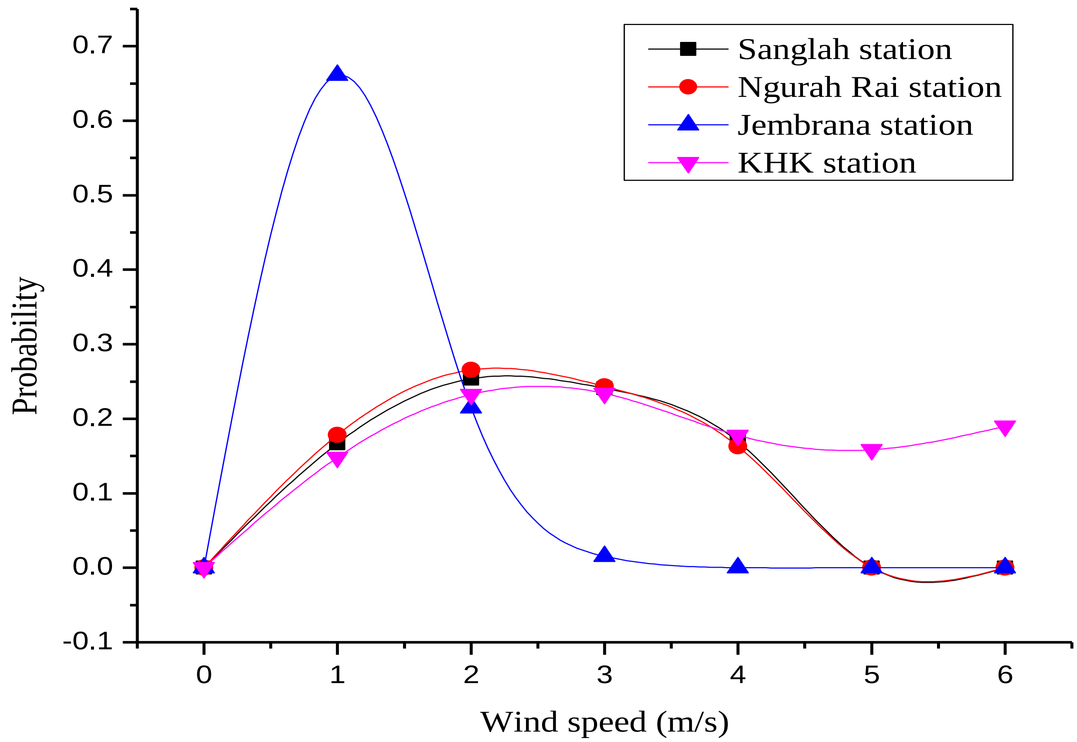

Figure 1. The Probability of wind speed.

The result from Figure 1 influnced by the shape parameters from Weibull, which the parameters is *K* an *C*, Weibull shapre parameter K presents without dimensions and C represent the parameters of the Weibull scale. Therefore, the characteristics of the different distribution and data can be modeled by changing the shape parameters from the Weibull distribution. Figure 1 shows the probability of velocity average each of BMKG stations in Bali. It can be seen that the highest probability of velocity in Bali is 2 m/s up to 4 m/s, even at a velocity of 5 m/s, the probability is very low (0.1-0.15) for each station. However, the West Bali has the lowest probability of velocity in Bali and East Bali has the highest probability of velocity in Bali. It doesn't rule out the possibility that the development of wind energy in Bali is very potential, depending on the are to be installed based on the source of wind probability in Bali.

A theoretical power has been represented by predicting wind farm power output for a given wind forecast. Therefore there are two important problems to handle. The first problem is how to deal with the substantial difference between the theoretical and experimental conditions of the wind turbine due to the location and site of the turbine, air density, temperature, average wind speed, wind direction, and also electrical and control issues. In this research, we develop an approach to modeling the equivalent power based on available wind and power output data from the BMKG. The data represent at below.

Table 4. The Stastistical result of the density and power on wind speed probability data in four BMKG stations (2012-2016).

BMKG Station	Year	Density (kg/m^3)	Power (W/m^2)
Sanglah	2012-2016	1.133495167	13.73978298
Ngurah Rai	2012-2016	1.173142439	12.73903793
Jembrana	2012-2016	1.174720189	0.959420783
KHK	2012-2016	1.174379381	29.53436739

The density and power were calculated to extending variable for the calculation of the wind density power in Bali. It shows that the KHK has the highest power generation based on the wind source statistical result using Weibull distribution. Regarding the result, I would mention that there are a few parameters after determining power and wind density power in this paper, it shows at Table 5 with concern about the reliability of the manufacture of the wind turbine based on the characteristics of the wind speed.

Table 5. The Statistical result of the regions wind speed on wind turbine.

BMKG station	Year	V cut in	V nominal	V cut out
Sanglah	2012-2016	2.315215438	6.614901251	9.922351876
Ngurah Rai	2012-2016	2.230671496	6.373347131	9.560020696
Jembrana	2012-2016	0.899313212	2.569466319	3.854199478
KHK	2012-2016	2.45009633	7.000275229	10.50041284

The turbine cut in and out are determined by the manufacturer to protect the turbine from damage. The V cut in speed is simple, it's the point at which the turbine starts generating the electricity from rotational of the rotor turbine. The cut out point is more important though and denotes how fast the turbine can go before wind speed getting so fast to rotational that it risk damage from further operation. The primary safety issue with wind speed comes from overspeeding, so some sort of stall or brake mechanism is needed to shut down the turbine before it takes a more damage. The Table 5 it shows the characteristics of the wind speed parameters, i.e. *V cut* in, *V nominal*, and *V cut out* that happen on each regional area in Bali, with capture data form four BMKG stations. It shows that area in around KHK stations has the more reliability potential source to build the wind turbine installation with V cut out reaches 10.5 m/s, and the other area have a potential to design the small wind turbine wih more capacity except the area on Jembrana stations, which the V cut out reaches 3.854 m/s.

Regarding the knowledge that it is critical for the assessment wind potential to know the power availability and therefore energy produced by the different type of wind turbine.

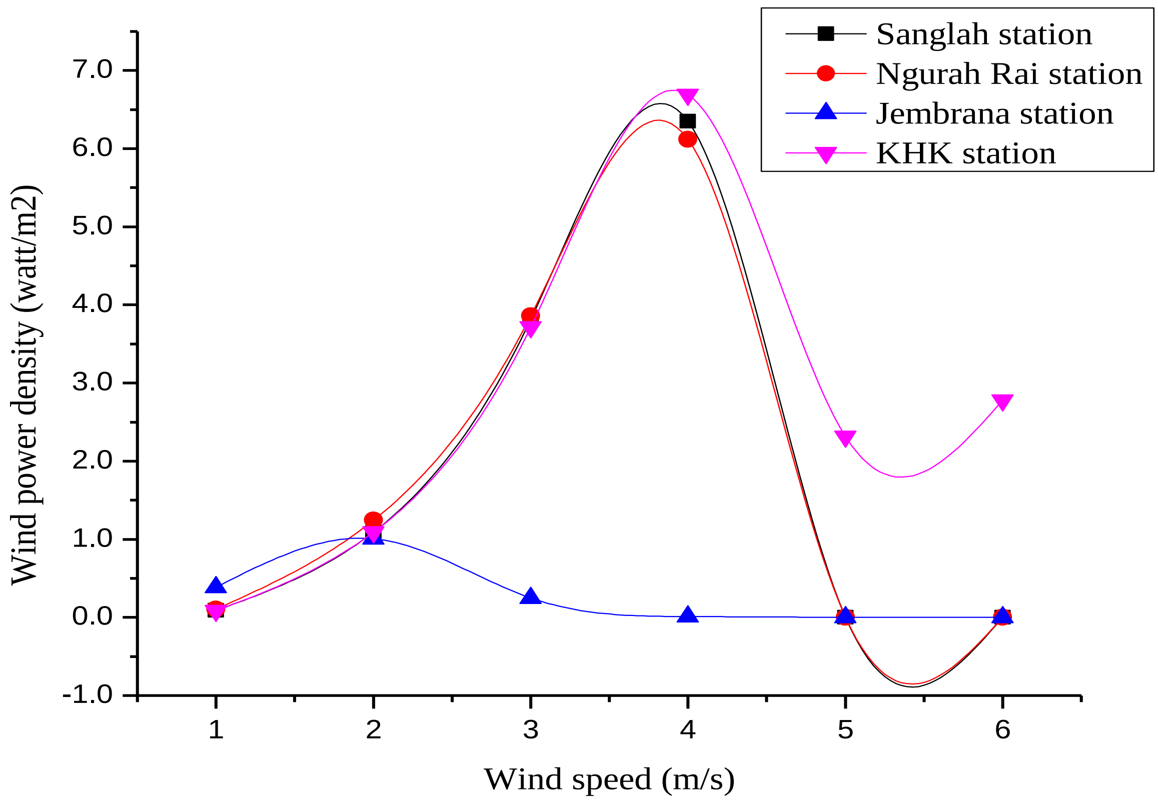

Figure 2. The probability of Wind density power.

Besides on the probability of velocity, the wind density power appears to explain the generated power based on the probability of the velocity average. The power density determined from the calculated the density distribution and it achieved from the configuration. The power density shows the stations that have maximum power densities occur on KHK station with 10.5 W/m^2. The same trend is shown in figure 2, where the west Bali has the best source among other regions, this reinforces, that the west Bali area is suitable to be used as the installation of small-scale wind turbine with the probability of wind density power, beside that the other districts (Sanglah station and Ngurah Rai station) have a potential to develop the wind turbine installation. Literally, the wind shear factor gives more impact to generated more velocity depending on the height of wind turbine installation and also the topography of the area to describes the condition of the area to give a good source and low resistance at the flow through on the installation. The Jembrana station has the lowest wind density power in Bali. It can generate power less than 2 Watt/m^2.

Table 6. The availability of wind speed (hours of the year) in four BMKG stations.

Wind speed (m/s)	Hours Sanglah	Hours Ngurah Rai	Hours Jembrana	Hours KHK
0	0	0	0	0
1	7208.19219	7710.30487	28560.45344	6389.26522
2	10958.58336	11476.26154	9277.41027	10048.37894
3	10407.40476	10520.98774	672.82812	10097.46645
4	7317.73471	7040.86466	12.9117	7683.98259
5	0	0	0	6843.81864
6	0	0	0	8212.58237

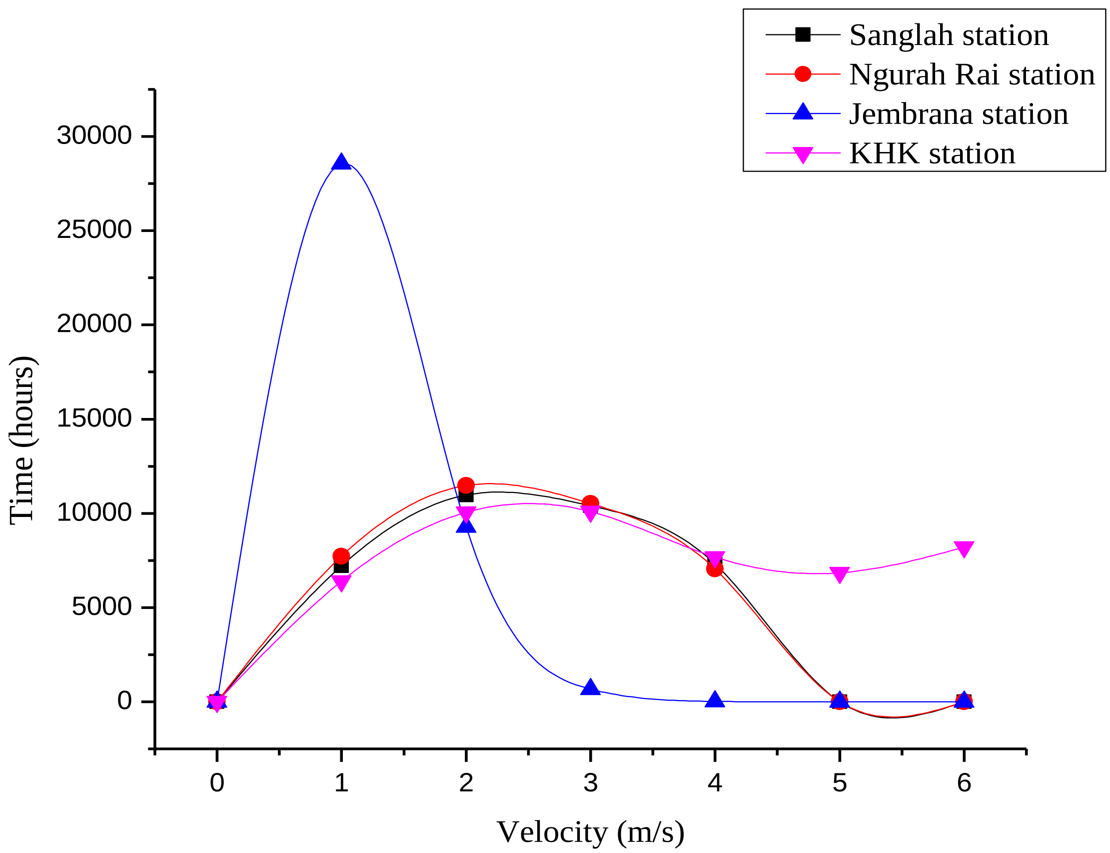

Figure 3. The availability of velocity in hours.

The availability of velocity average on each station gives an impact to know the total of the velocity available for in one year. Figure 3 shows similar trend with the probability of the velocity average, However this variable is not likely the most important variable to design the wind turbine, because of this case, the rate of velocity will increase according to the height of the rotor turbine, hence the possibility of the velocity average will consider being one of first policy to calculate the other factor to increase the performance of the wind turbine installation [5].

Study of Installed Wind Turbine Technology at Bali

There are several wind turbines technologies have been installed and even operate in the area, including in South Bali (Jimbaran) which amounted to 10 prototypes and another site on the middle area (Denpasar), which amounted to 8 prototypes, but there are some problems that occur during the operation of the wind turbine prototype. The experimental condition from power output systems shows that the power can generate power as a by design.

The data that has been obtained, the value of velocity that at the height of the installed wind turbine can be calculated as below:

Table 7. The spesification of wind turbine installation in South Bali (Jimbaran).

Fabrication	Wind turbine #1	Wind turbine #2
Wind shear (m/s)	3. 224	3. 224
Wind density power (W/m2)	34.66	61.62
Prototype	8	2
Total power (W/m2)	277.28	123.24
Rotor stress	1.13	1.17

Thus, the velocity at a height of 12 m is 3.224 m/s. From these data, it is continued with the rotor stress calculation to know the voltage/tension that will be happen on the rotor turbine during its operation at installed height = 1.17 The power in the wind at the top tip rotor is 13% turbine #1 and 17% for turbine 2# which that mean, higher than it is when the tip reaches its lowest point.

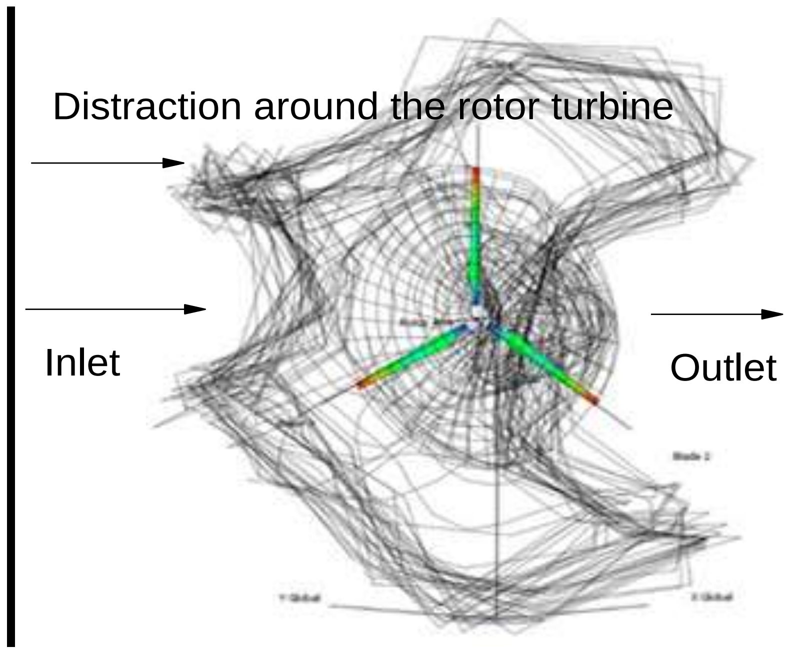

Figure 4. Wind turbine rotational with actual condition.

Q-blade has been represented on this design to visualization the real condition on the installation [27] at the first site in South Bali (Jimbaran). It can be seen that the resulting of rotation is low so that the interaction between the rotor boundary layer and the free stream air makes the system unable to extract more wind power and it causes the resulting performance to be distraction, because the simulation data in generating power is not much different from the results in the actual data from monitoring system. However, after redesigning on the construction of the wind turbine, it has shown the wind turbine power definitely increases and the result shows the similar result from theoretical data. Currently, the diameter of the rotor is shorter than the previous design. Almost same as that had been done in Electrical Engineering, Udayana University, which determines the area of the turbine to be installed later, where for the provincial government of Bali has the value friction coefficient of 0.40, because in that region is a very dense region especially in Bali. The location of the wind turbine has been installation located in Denpasar city, where the BMKG Sanglah station oversees the city, so the probability of the average velocity obtained is 3.31 m/s with an average density is 1,0948 kg /m3, with a tidal height of 18 m. From some data that has been obtained, then the value of velocity at the height of the installed wind turbine can be obtained with the equation:

So the velocity at a height of 18 m is 5.03 m/s. From these data, it is continued with the stress rotor calculation to know the voltage/tension that will be experienced by the turbine rotor during its operation at installed height [7], that is:

Table 8. The spesification of wind turbine installation in Middle (Denpasar).

Fabrication	Wind turbine #1
Wind shear (m/s)	5.03
Wind density power (W/m2)	46.52
Prototype	8
Total power (W/m2)	372.16

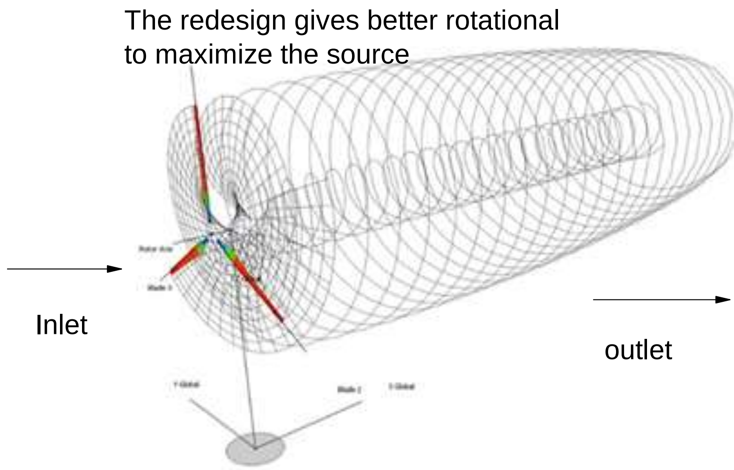

Figure 5. Wind turbine rotational with redisign based on the wind speed probability.

Based on the redesign, where the power obtained based on the simulation of 119.9 w/m2, the value of the simulation results is closer with the theoretical i.e. 123 w/m^2. It shows that the resize of the wind turbine design giving a promising to extract more power with the availability of wind energy at the area, the rotational will increase the effectiveness of the system, hence the coefficient of the performance show a good value with 0.56 from the simulation. Before the simulation, the design has been showed that the performance decrease with coefficient of performance (Cp) 0.23, it means that the rotor turbine can extract power up to 23 % based on the wind density power[17]. so that studies carried out based on average wind speed probability have a positive impact on installed installations but do not produce performance that does not match expectations, so that in the future this study will be used as a reference in determining wind turbine installation locations based on the average wind speed probability in Bali.

CONCLUSIONS

This research evaluated the probability of velocity average in Bali give a provides that the Jembrana Station has the lowest probability of velocity average and wind density power than the other stations in Bali, however the other stations have good potential resources to implement the wind turbines installation with adjustment the highest probability of velocity. Currently, the assessment of wind turbine systems that had been installed in Bali must be reconstruction to improve the performance to generated more power from the wind source in Bali with disparage the diameter of rotor and given the pitch control to adjustment the angle of attack form freestream air to generated the power of turbine, and also the wind shear factor from the location of wind turbine installation would be determined to know the optimizing of the height of wind turbine installation based on the condition and topography of the location. Hence in the future, the data will be used for the feasibility study from energy potential of wind energy in Bali. This is a auspicious decision for a district where people are trying to reach energy-independent constructions because of a shortage of electricity serving in the local grid. Our future research will focus on learning instrumentation control on wind turbines and high effects in pratice through measurement. This study would available for searching best suggestion to growth the wind source development in Bali, Indonesia, which has not been ultilized so far.

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