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Study on Wind Speed Correlation between UNITEN and Meteorological Station Data for Wind Resource Assessment

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ABSTRACT

Assessing the wind speed at a target site is essential in deciding the feasibility of wind turbine installation for energy production. However, doing on-site measurement alone requires a long period of data collection to capture the annual and seasonal changes of wind speed. One of the method used to overcome to issue is by using the correlation method, by measuring a small set of data at a target site and correlating with the data at a nearby site, either a meteorological station or an airport, which usually have long-term records of wind data. This paper discusses a study done at Universiti Tenaga Nasional located in Kajang, Malaysia, on the suitability of using a nearby long-term data for its wind resource assessment. It is shown that the correlation coefficient (r) is 0.71 and its coefficient of determination (R^2) is 0.51. 23 of the data recorded at the target site out of 26 data points or 88.46% shows higher wind speed compared to the reference site which is the meteorological station.

Keywords: Wind Resource, Wind Correlation, Wind Speed, Resource Assessment

I. INTRODUCTION

The concern for climate change and recent instability of fossil fuel prices has catalyzed the effort of reducing carbon emission caused by energy production and consumption. On the supply side of energy, Renewable Energy has gain significant capacity in the world's energy mix, with encouraging annual increase. This can be attributed to international agreements such as Kyoto Protocol, COP15 and Paris Summit agreement and reflected through policies by governments such as introduction of Feed-in-tariff and other incentives. Renewables 2016 Global Status Report categorizes into five main categories which are Bioenergy, Geothermal, Hydropower, Solar Energy and Wind power [1], with further sub-categories, which can be summarized as follows:

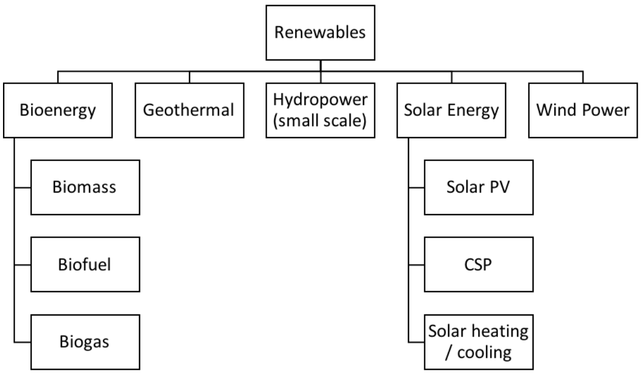

Figure 1: Types of Renewables (source of information: Renewables 2016 GSR [1])

Malaysia has not been behind in joining the global effort in combating climate change. Malaysia has made voluntary commitment to reduce greenhouse gases up to 45%, with 35% unconditionally and further 10% with support from advanced countries in terms of financing, technological transfer and capacity building [2]. Malaysia has started to recognize Renewable Energy as the fifth fuel for its national energy mix in the year 2000, in the Eight Malaysia Plan [3]. This is followed by several other efforts, including introducing Acts, Policies and Studies. One of the important drivers of Renewable Energy in Malaysia was the introduction of Feed-in-tariff (FiT) in 2011 [4], which has shown tremendous growth of Renewable Energy capacity in Malaysia. The first four FiT introduced was for solar, biomass, biogas and small-hydro and later in 2015, Geothermal was included [5]. However, up to 2017, Wind Energy has not been included for Feed-in-tariff [6]. This can be contributed to the general understanding that there is low availability of wind speed in Malaysia. However, a study by Lip-Wah Ho stated concluded that previous studies on wind speed are grossly inaccurate and suggested mesoscale measurement using higher pole mast [7].

Wind energy captures the movement of air in the form of kinetic energy and converts into electricity, usually using electro-mechanical device such as generator. The conversion of energy is using this formula:

$$P_{turbine}(u) = C_P \times \frac{\rho A u^3}{2}$$

Where $P_{turbine}$ (u) = power output of wind turbine; A = rotor swept area; ρ = air density and C_P = power coefficient [8].

In reality, Cp is physically limited to the Betz limit as the maximum efficiency which states that the maximum conversion of wind to energy by wind rotor is 59.3% [9]. Taking into account the mechanical efficiency of conversion device, it is usually in the range of 0.3 to 0.4.

There are various types of wind turbines devices available to convert wind energy to electrical energy. They are generally categorized into two, which are Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Comparison has been made by Eriksson [10] and concluded several advantages of VAWT. VAWT has lower coefficient of performance and starting torque, however works better on roof tops, can generate electricity omnidirectionally so it requires no yaw mechanism, having less mechanical stress due to its self-supporting ability, lower maintenance and less noisy [10]. However HAWT are more widely used due to its higher efficiency.

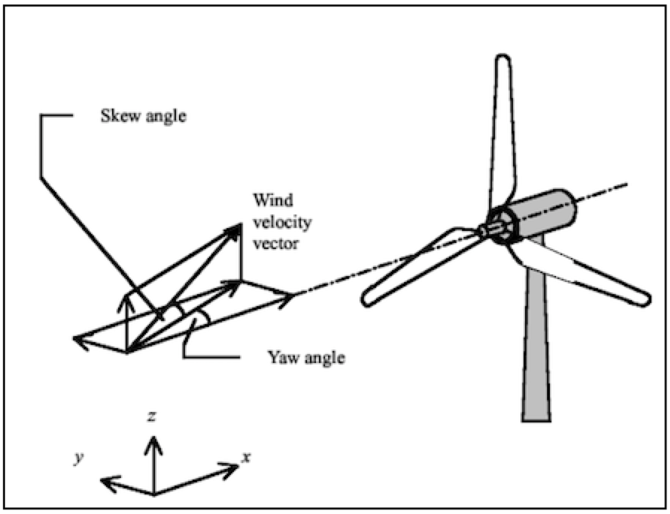

Figure 2: Horizontal Axis Wind Turbine[11]

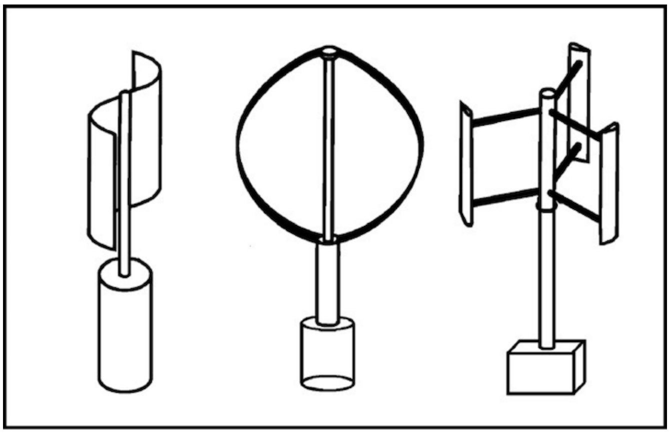

Figure 3: Types of VAWT (Savonious, Darrieus and H-rotor types)[10]

Building-integrated wind turbine can offer the means of electricity production without additional use of land space. To assess the wind speeds on rooftops, two problems are involved, which are assessing the wind resource in the area and the effect of the shapes of building envelopes [12]. A study by Abohela et al. shows the effect of different roof shapes on the wind flow of roof tops [13].

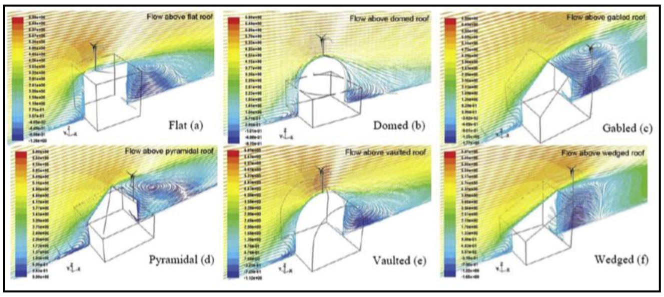

Figure 4: Optimal mounting location for different roof shapes [13]

Walker cited Lanberg et al. on the methods of estimating wind speeds, which can be categorized into three, which are i) measurement, ii) measure-correlate-predict iii) and Wind Atlas Data [14]. Each of these methods have their own advantages and disadvantages. Site measurement is the most accurate to assess the site wind resource, however this involves installing a measurement device on site and long period of data needs to be collected. The second method, measure-correlate-predict requires smaller set of data. Carla et al. has reviewed this method extensively and it involves smaller set of data, relying on the relationship between the recorded wind speed at the site and a target site nearby which has longer period of data [15].

This paper discusses a study done on the correlation method of assessing wind on a rooftop at Universiti Tenaga Nasional located in Kajang, Malaysia. Part 2 of this paper will explain the methodology, followed by Part 3 which will present the results and discussion.

II. METHODS AND MATERIAL

Figure 5 : Location of Target Site and Reference Site

Figure 5 shows the location of reference site and target site for the correlation study. The reference site is a Malaysian Meteorological Department, which has the long term data and site data, which is the roof top of Administration Building, Uniten. Wind speed and direction data was collected for four days on 21, 22, 23 and 24 November 2016, using anemometer placed on a tripod to increase the height of the sensor, to avoid low pressure and turbulence area on the rooftop.

Concurrent wind speed data from Malaysian Meteorological Department, Pusat Pert. Serdang station was purchased for wind speed correlation study to determine the suitability of using the reference site data for long term prediction.

The sensor records data at around 0.4 seconds/time as shown in Table 1. This data is then averaged for every hour, to equate the period between the recorded data and the reference data, which is averaged hourly.

Table 1: Sample of data recorded from the wind sensor

No.	Unit	Date	Time
1	m/s	24/11/2016	9:44:50 AM
2	m/s	24/11/2016	9:44:51 AM
3	m/s	24/11/2016	9:44:52 AM
4	m/s	24/11/2016	9:44:52 AM
5	m/s	24/11/2016	9:44:53 AM
6	m/s	24/11/2016	9:44:54 AM
7	m/s	24/11/2016	9:44:55 AM
8	m/s	24/11/2016	9:44:56 AM

Pivot table is used to summarize the recorded data into hourly mean for each daily wind speed data recorded at the site. Pivot tool is an in-built tool in Microsoft excel.

The data between the target site and reference site was then correlated to find the r coefficient and R^2 coefficient. The equation to obtain r and R^2 are as follows [15]:

$$r = \frac{\sum_{i=1}^{n}[(v_i)_t^{ST} - (\bar{v})_t^{ST}]^1[(v_i)_r^{ST} - \bar{v}_r{}^{ST}]^1}{\{\sum_{i=1}^{n}[(\hat{v}_i)_t^{ST} - (\bar{v})_t^{ST}]^2\}^{1/2}\{[(\hat{v}_i)_r^{ST} - (\bar{v})_r^{ST}]\}^{1/2}}$$

$$-1 \le r \le 1$$

$$R^2 = \frac{\sum_{i=1}^{n}[(\hat{v}_i)_t^{ST} - (\bar{v})_t^{ST}]^2}{\sum_{i=1}^{n}[(v_i)_t^{ST} - (\bar{v})_t^{ST}]^2}$$

Where:

$(v_i)_r^{ST}$ = short-term wind speeds observed at the reference site;

$(\hat{v}_i)_r^{ST}$ = observed short-term wind speeds at reference site;
$(\bar{v})_r^{ST}$ = short-term mean wind speed measured at the reference site;
$(\hat{v}_i)_t^{ST}$ = estimated short-term wind speeds of the target site;
$(\bar{v})_t^{ST}$ = short-term mean wind speed measured at the target site;
$(v_i)_t^{ST}$ = short-term wind speeds observed at the target site

III. RESULTS AND DISCUSSION

Table 2: Wind speed on Day 1

21-Nov-16		
Hour	**Average Wind Speed (m/s)**	**Wind Speed at Ref. Site (m/s)**
9:00 AM	0.98	0.6
10:00 AM	0.84	0.9
3:00 PM	3.7	2.7
4:00 PM	3.04	2.5
Min	0	
Max	7.71	
Average	2.02	

Table 3: Wind speed on Day 2

22-Nov-16		
Hour	**Average Wind Speed (m/s)**	**Wind Speed at Ref. Site (m/s)**
9:00 AM	1.33	0.7
10:00 AM	0.78	0.7
12:00 PM	4.48	1.6
3:00 PM	1.7	1.1
4:00 PM	1.78	0.8
Min	0	
Max	9.41	
Average	1.592	

Table 4: Wind speed on Day 3

23-Nov-16		
Hour	**Average Wind Speed (m/s)**	**Wind Speed at Ref. Site (m/s)**
8:00 AM	1.77	0.5
9:00 AM	1.42	1
10:00 AM	1.61	0.8
11:00 AM	1.34	0.9
12:00 PM	0.98	1.2
1:00 PM	3.26	2.2
2:00 PM	2.91	2.1
3:00 PM	3.95	1.7
4:00 PM	4.36	1.6
5:00 PM	3	1.4
Min	0	
Max	8.1	
Average	2.65	

Table 5: Wind speed on Day 4

24-Nov-16		
Hour	**Average Wind Speed (m/s)**	**Wind Speed at Ref. Site (m/s)**
9:00 AM	1.72	0.5
10:00 AM	1.22	0.8
11:00 AM	1.03	0.9
12:00 PM	1.23	1.5
1:00 PM	2.17	1.3
2:00 PM	2.44	1.7
3:00 PM	2.09	1.8
Min	0	
Max	5.26	
Average	1.68	

Table 2 to Table 5 shows the wind speed recorded for four days between 21st – 24th of November 2016. On Day 1, wind speed was measured for the hour of 9.00 – 10.00 a.m. and 3.00 – 4.00 p.m. The minimum wind speed recorded was 0 m/s which is calm and the maximum was 7.71 m/s. On Day 2, wind speed was measured for the hour of 9.00 a.m. – 12.00 p.m. and 3.00 – 4.00 p.m. The minimum wind speed recorded was 0 m/s which is calm and the maximum was 9.41 m/s, which was the highest recorded for all four days. On Day 3, wind speed was measured for the hour of 8.00 a.m. – 5.00 p.m. The minimum wind speed recorded was 0 m/s which is calm and the maximum was 8.1 m/s. On Day 3, wind speed was measured for the hour of 9.00 a.m. – 3.00 p.m. The minimum wind speed recorded was 0 m/s which is calm and the maximum was 5.26 m/s, which is the lowest maximum speed recorded throughout the four days. Concurrent wind speed of the reference site was obtained for the all hours recorded.

Table 6: Summary of Data for All Recorded Days

Sample	**Time**	**Data site (m/s)**	**Data Reference (m/s)**
1	9 AM	0.98	0.6
2	10 AM	0.84	0.9
3	3 PM	3.70	2.7
4	4 PM	3.04	2.5
5	9 AM	1.33	0.7
6	10 AM	0.78	0.7
7	12 PM	4.48	1.6
8	3 PM	1.70	1.1
9	4 PM	1.78	0.8
10	8 AM	1.77	0.5
11	9 AM	1.42	1
12	10 AM	1.61	0.8
13	11 AM	1.34	0.9
14	12 PM	0.98	1.2
15	1 PM	3.26	2.2
16	2 PM	2.91	2.1
17	3 PM	3.95	1.7
18	4 PM	4.36	1.6
19	5 PM	3.00	1.4
20	9 AM	1.72	0.5
21	10 AM	1.22	0.8
22	11 AM	1.03	0.9
23	12 PM	1.23	1.5
24	1 PM	2.17	1.3
25	2 PM	2.44	1.7
26	3 PM	2.09	1.8

The data for all four days combined gives 26 points of data, with the concurrent wind speed obtained from the reference site. These points are then used to generate a linear regression plot, to which its coefficient of determination or R^2 is obtained:

$$R^2 = 0.50847$$

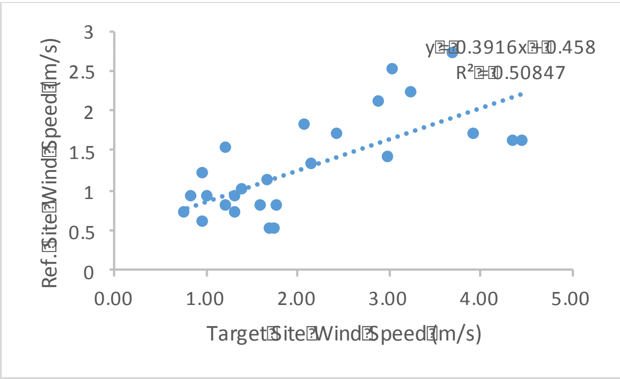

Figure 6: Linear Regression Plot to Obtain Coefficient of Determination

Table 7: Regression Statistics

Regression Statistics	
Multiple R	0.71
R Square	0.51
Adjusted R Square	0.49
Standard Error	0.80
Observations	26

The value of R^2 is considered to be low meaning that the regression is relatively unsuitable to be used for forecasting or prediction. However, its linear coefficient or is 0.71, showing good correlation of data between the sites.

It can be seen that lower wind speed, the data points are closer to the linear regression line, and further away scattered at higher wind speed. More data is concentrated at lower wind speed, below 2 m/s. Out of 26 points of data, 23 points or 88.46% show that the speed at the target site is higher than the speed at the reference site.

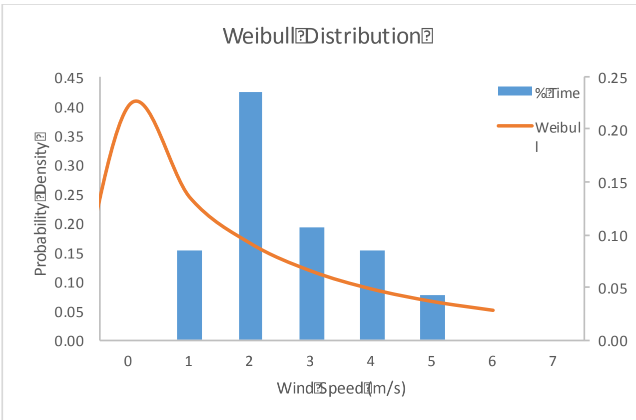

Figure 7: Wind speed distribution

The wind speed distribution shows that wind speed at 2m/s has the highest probability density, meaning the highest occurrence of wind speed, followed by wind speed at 3 m/s, 1m/s, 4 m/s and 5 m/s. It is noted that this is the distribution of hourly mean wind speed, thus not capturing higher wind speed that occurs, up to 9.41m/s recorded. From the Weibull distribution, it can be seen that the line is skewed to the left, meaning that the probability of having low wind speeds is higher. Taking the highest occurrence of wind speed of 2m/s, the available power and annual energy in the wind speed is calculated to be:

$$\text{Power} = \frac{1}{2} \times \frac{1.225\text{kg}}{\text{m}^3} \times \left(\frac{2\text{m}}{\text{s}}\right)^3 = 4.9\text{W/m}^2$$

$$\text{Annual Available Energy} = \frac{4.9\text{W}}{\text{m}^2} \times 8760\text{hours} = 42.92\text{kWh/m}^2$$

Assuming a turbine with a swept area of 1m^2 and coefficient of performance to be 0.3, the annual electricity production is:

$$\text{Energy} = \frac{42.92\text{kWh}}{\text{m}^2} \times 1\text{m}^2 \times 0.3 = 12.87\text{kWh}$$

IV.CONCLUSION

The study has shown the wind speed availability on the rooftop of the target site, showing the highest wind speed recorded to be 9.41m/s and averaging around 2m/s. Most of the data currently available is averaged for a long period of time, which is usually hourly, daily, monthly or annually. This averaging process omits the higher wind speed available, hence the higher power output available at a point of time. Out of 26 points of data, 23 points or 88.46% show that the speed at the target site is higher than the speed at the reference site, showing the importance of on-site data measurement to evaluate the wind resource at the target site. The wind speed correlation between target site and reference site was studied and the correlation coefficient is 0.71, and coefficient of determination to be 0.51, which is considered low for prediction. For future work, the number of data sets should be increased and recorded for a longer period of time, and multiple correlation with more than one reference site should be considered to improve the correlation and coefficient of determination.

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