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Feasibility Study of Wind Energy Harvesting at TELCO Tower in Malaysia

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ABSTRACT

As the stride towards 5G intensifies in Malaysia, more Base Transceiver Stations (BTS) will be erected to fulfill the infrastructural needs. BTS tend to be built in isolated areas rendering tapping power from the main grid to be an economically unpleasant option. In Malaysia, the potential of wind energy as an energy source is largely untapped due to the relatively low average wind speed. However, BTS may not need a huge amount of power to function. Hence, this paper investigates the feasibility of application of small wind turbines (SWT) to fulfill the power needs of a typical BTS. The power consumption of a typical BTS would first be estimated followed by estimation of the power yield of few commercially available SWT's. Based on available wind data, it was found that the power generated from SWT is insufficient to match the power demand of a typical BTS.

Keywords: Small Wind Turbine, Wind Energy, Base Transceiver Station
JEL Classifications: Q42, Q47, Q56

1. INTRODUCTION

In recent decade, the information and communication technology (ICT) sector has advanced tremendously. This exponential growth of demand has prompted the telecommunication operators to set up additional base transceiver stations (BTS) to expand the cellular network coverage areas (Alsharif et al., 2017). Between 2007 and 2012, the number of BTSs worldwide has increased rapidly and has exceeded beyond more than 4 million today (Wu et al., 2015). This increment of BTSs has remarkably increased energy consumption due to the stations accounting for 57% of the total consumed energy in mobile cellular networks (Wu et al., 2015; Hasan et al., 2011). As the result, the operational expenditures (OPEX) of mobile cellular networks have also increased.

In many countries with Malaysia being no exception, the mobile cellular network operators tend to use fossil fuel generator to supply the BTSs due to the geographical limitation. However, this will increase the OPEX by 10 times for long term usage (Aris and Shabani, 2015). The network companies are seeking a viable option instead of using fuel generator to power BTSs in rural areas which can maintain the company's profitability but also minimize the negative impact to the environment through the operation (Kusakana and Vermaak, 2013). Because of the anticipated economic and ecologic influence, the researchers and network operators have been forced to face the challenges of improving energy efficiency in the coming year. Hence, the relatively new research and technology "green communication" was introduced (Wu et al., 2015).

Fast growth in renewable energy has been evident in recent year. In the context of increasing energy demand and environmental pollution, renewable energy resources such as solar and wind have become a crucial source in supply-side planning. The use of green energy can contribute to a reduction of fossil fuel consumption of base transceiver stations. Such solutions of BTSs powered by green energy has brought a new trend in the ICT sector. A number of wind farms have been built all over the world but there are also a number of projects is delayed because of the unwanted effects such as acoustic disturbance and EM interferences. More specifically, the radio propagation like radars and satellite will be affected by the electromagnetic interference of the wind turbine, which is one of the critical reason. This impact has been researched since 1970's and is still ongoing (Gavin, 2003). Apart from normal wind turbines (WTs), small wind turbine (SWT) of has been introduced to power homes and commercial needs. Notably, the use of wind energy to power the BTSs is a satisfactory solution to promote to reduce fuel consumption while the BTSs are located in the off-grid service areas. The advance technologies in renewable energy nowadays can provide the specific needs such as efficiency, cost-effectiveness, sustainability and reliability in power supply for rural BTSs (Kusakana and Vermaak, 2013). These technologies might open to hundreds of millions of potential customers. Besides, the operator can optimize their operating cost and have a positive impact on environment in reducing harmful gases by implementing renewable energy. In order to improve the network penetration nationwide, many BTSs are installed in remote and severe areas. Unlike wind farms, these remote site often have limited area which renders using normal wind turbine to harvest wind energy to be impractical. Hence, it is the objective of this paper to investigate on the application of SWT to meet the power demand of BTS. In many ways, there are many benefits to using a SWT such as low cost, easy to install, lower failure rate and low electromagnetic interference.

The remaining of the investigation is outlined as follow. Section two will introduce the wind energy. Section three will present the wind data in Malaysia and types of SWT considered in this study. Finally, section four will show the theoretical findings and results explanations. Lastly, section five will summarize the investigation with conclusions and recommendations.

2. LITERATURE REVIEW

2.1. Equipment

The growth of the population leads to the increasing demand on telecommunication side all around the world. The increasing demand force the mobile operator to ensure good signal coverage throughout the country which necessitates the installation of large number of base transceiver stations (BTSs). The power consumption of base transceiver stations in remote areas has attracted attention amongst the mobile network operators in long-term consideration. In recent years, the trend of green energy growing rapidly and significantly as an important option in supply-side planning. This trend has shown that the "green" technology is now approaching a mature and advance stage, and it is still ongoing and improving. Hence, many network operators have confidence in this technology. In order to have a sustainable development, the use of renewable energy to power the BTSs have gained the interest of the cellular operator. Table 1 summarises the common equipment in a typical BTS.

2.2. Wind Energy

The kinetic energy generated by the wind is captured and transformed to mechanical energy through wind turbines in order to generate electricity (Ibrahim and Yong, 2015). There are several factors that affect the power gained from windmills. The energy produced by the wind turbine converts the flowing wind speed into mechanical then electricity.

The kinetic energy of a mass in motion is:

$$E = \frac{1}{2} m v^2 \tag{1}$$

The power in the wind is given by the rate of change of energy:

$$P = \frac{dE}{dt} = \frac{1}{2} v^2 \frac{dm}{dt} \tag{2}$$

As the mass flow rate is given by:

$$\frac{dm}{dt} = \rho A \frac{dx}{dt} \tag{3}$$

And the rate of change of distance is given by:

$$\frac{dx}{dt} = v \tag{4}$$

We get:

$$\frac{dm}{dt} = \rho A v \tag{5}$$

The power contained in the wind kinetic energy can be defined as:

$$P_w = \frac{1}{2} \rho A v^3 \tag{6}$$

Where P_w: Wind Power (W); ρ : Air density (kg/m^3), less in higher altitude; A: Swept rotor area (m^2); v : Wind speed (m/s).

According to Betz' Law by a German physicist Albert Betz concluded in 1919, "even with the ideal wind energy conversion, the maximum power transferrable is only 0.593 (59.3%) or 16/27 of the total power in the wind." Since the ideal theoretical power coefficient (C_p) implies that a maximum of 59.3% of the power from the wind can be extracted, the electrical power can then be expressed as (Royal Academy of Engineering, 2010):

$$P_{max} = 0.593 \cdot P_w \tag{7}$$

Where P_{max} : Maximum output power that can be extracted (W); C_p : 0.593 (Ideal).

Yet, none of a turbine can operate at this maximum limit. For each turbine type, there is a unique C_p value and it is a function of wind speed at which the turbine is operating in. When taking in the consideration of various engineering requirements like strength and durability of a wind turbine, the practical limit is much lower than Betz Limit with values of 0.35-0.45, which is very common in the event of a better-designed turbine (Royal Academy of Engineering, 2010). Once all kinds of factors are taken into account, only 10%-30% of the wind power is converted into usable electricity. Thus, the power coefficient needs to be factored into the equation (1) and the power that can be extracted from the wind is given by:

Table 1: Type of equipment

Components		Description	Power consume	Percentage
Main Equipment	Transceiver (TRX)	Deal with the signal transmission and reception of signals.	≈500W-800W	25%-45%
	Power Amplifier	Aids in signal amplification from TRX for transmission through the antenna.		
	Duplexer	Detaching the sending and receiving signal to or from antenna.		
	Combiner	Combine feeds from several TRXs, reduced the number of antennas that need to be installed.		
	Control Unit	Control and manage various unit of BTS.		
	Baseband Unit	Perform DSP, encoding decoding.		
	Battery Bank	Supplies the equipment with the electrical power and security light and alarm.		5%-10%
Optional	Air Conditioner	Reduce the temperature as a result of the heat generated by the components.	(if required for a 12' × 10' cabin, 1-2 HP) ≈1.8kW-2kW	45%

$$P_{ex} = C_p \cdot \frac{1}{2} \rho A v^3 \tag{8}$$

Where P_{ex} :Actual power that can be extracted (W); C_p :Maximum power coefficient, range 0 ″ C_p ″ 0.4 (Practical)

Thus, a coefficient can be defined to express the effectiveness of a wind turbine. This unique value from the turbine is called power coefficient or the Betz factor and can be expressed as:

$$C_p = \frac{Turbine\ Power}{Power\ of\ Wind} \tag{9}$$

Power coefficient, is a function of two variables, tip speed ratio *λ*, and pitch angle *β*. Tip speed ratio is the ratio of the speed of the tip of the blade, *ωR*, to the velocity of wind, *v*. Here, *ω* represents the radius of the turbine blade.

$$\lambda = \frac{\omega R}{\beta} \tag{10}$$

2.3. Power Law

In wind energy studies, two types of wind profile laws are commonly used for vertical extrapolation of wind speeds *u*(*z*) in the atmospheric surface-layer. The power law is an empirical formula for the mean velocity profile (Daniel et al., 2013). The formula is based on finding the magnitude of the exponent, α, which provides the best fit of wind speed observations between two heights (Daniel et al., 2013), the formula is:

$$u(z) = u(z_1)(\frac{z_2}{z_1})^{\alpha} \tag{11}$$

Where $u(z_1)$: Velocity of wind at height z_1 (ms^{-1}); $u(z)$: Velocity of wind at height z_2 (ms^{-1}); z_1: Lower height (m); z_2: Upper height (m); *α*: Wind shear exponent (Trevor, 2005).

2.4. Log Law

The Log wind profile is a semi-empirical equation generally used to describe the vertical distribution of horizontal mean wind speeds within the lowest portion of the atmosphere (Oke, 1987). The increase of wind speed with height in the lowest 10 m < z < 100 m can be expressed by this logarithmic expression:

$$u_z = \frac{u_*}{k}[\ln(\frac{z-d}{z_0}) + \psi(z, z_0, L)] \tag{12}$$

u_* : friction velocity (a reference wind velocity) (ms^{-1}); *k*: Von Karman Constant, *k* = 0.4; *d*: zero plane displacement (m), Z_0: roughness length (m); ψ : stability correction factor, (= 0 for statically neutral conditions); *L*: Obukhov length; Z_0: Roughness length (m).

Under neutral stability conditions, $z / L = 0$ and ψ can be dropped so that the equation is simplified to,

$$u_z = \frac{u_*}{k}[\ln(\frac{z-d}{z_0})] \tag{13}$$

Zero-plane displacement (*d*) is the height above the ground at which zero wind speed is achieved as a result of flow obstacles such as trees or buildings. It is generally approximated as $^2/_3$ of the average height of the obstacles.

Roughness length (z_0) is a corrective measure to account for the effect of the roughness of a surface on wind flow, and is between $^1/_{10}$ and $^1/_{30}$ of the average height of the roughness elements on the ground.

At the lowest 10–20 m of the planetary boundary layer, the log wind profile is generally considered to be a more reliable estimator of mean wind speed than the wind profile power law (Cook, 1985). With increasing height between 20 m and 100 m both laws represent its reasonable predictions of mean wind speed in neutral atmospheric conditions (Cook, 1985; Cook, 1997). From 100 m to the top of the atmospheric boundary layer, the use of power law may produce a more accurate estimation of mean wind speed (assuming neutral atmospheric conditions) (Cook, 1985). However, the log law may not be accurate for heights above 200 m (Tieleman, 2008; Li et al., 2010).

3. METHODOLOGY

Table 2 shows the Malaysia weather report from during period 2005-2015. The data show the average temperature, pressure, dew point and wind speed for each state over 12 months. From the table below, the data obtained from the weather report is based on weather station, and the wind data is collected at a height of 10 meters. In general, the mean annual wind hardly exceeds 2 m/s in Malaysia. The wind speed varies by region and month. Malaysia is located at the

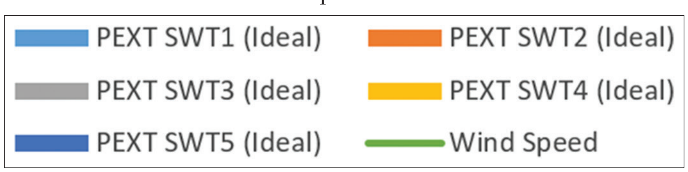
Table 2: Malaysia weather report during period 2005-2015

State	Weather Station	Mean Temp. (°C)	Humidity (%)	Dew Point (°C)	Air Pressure (hPa)	Wind Speed (m/s)
Johor	Averages are for Singapore/Paya Lebar, which is 19 kilometers from Johor Bahru.	28.417	80	24.167	1009.634	2.33
Kelantan	Averages are for Kota Bharu Airport, which is 7 kilometers from Kota Bharu.	27.5	81.75	23.75	1010.144	2.33
Pahang	Averages are for Kuantan, which is 24 kilometers from Kuantan.	27.583	85.25	23.833	1010.101	1.917
Penang	Averages are for Penang/Bayan Lepas, which is 14 kilometers from George Town.	28	81.083	24.083	1009.813	2
Terengganu	Averages are for Kuala Terengganu, which is 7 kilometers from Kuala Terengganu.	27.417	81.75	23.75	1010.144	2.33
Negeri Sembilan	Averages are for Sepang/KL International Airport, which is 26 kilometers from Seremban.	28.333	80.083	23.83	1009.794	2
Melacca	Averages are for Malacca, which is 8 kilometers from Malacca City.	27.83	82.083	23.83	1009.945	1.75
Kedah	Averages are for Alor Setar, which is 66 kilometers from Satun.	28.417	77.83	23.583	1009.279	0.33
Perak	Sitiawan	27.75	84.417	22.167	1009.898	1
Perlis	Averages are for Kangar, which is 59 kilometers from Hat Yai Airport.	28.167	80	23.167	1009.981	1.5
Selangor	Averages are for Shah Alam, which is 7 kilometers from Sultan Abdul Aziz Shah-Subang.	28.33	80.5	23.83	1009.829	1.83
Sarawak	Averages are for Kuching Airport, which is 9 kilometers from Kuching.	27.417	85.67	23.583	1010.045	1.08
Sabah	Averages are for Kota Kinabalu, which is 6 kilometers from Kota Kinabalu.	28	81.583	24	1009.563	2

Table 3: Characteristic of five type of small wind turbine

No.	Company	Model	Rotor Diameter (m)	Swept Area (m^2)	Rated Power (W)	Cut-in Wind Speed (m/s)
SWT 1	Zephyr Corporation	Airdolphin Pro	1.8	2.545	674	2.0-2.5
SWT 2	Eclectic Energy Ltd	Stealth Gen D400	1.1	0.95	400	1.5-2.0
SWT 3	Vaigunth Ener Tek (P)	AR-500w	2	3.14	500	2.5-3.0
SWT 4	Fortis Wind Energy	Espada/0.8kW	2.2	3.801	800	2.0-3.0
SWT 5	A-WING International	YWS-500 Wind Luce	1.558	1.906	500	1.0-1.5

Figure 1: The Bar chart represents the power generated by 5 turbine with respective color



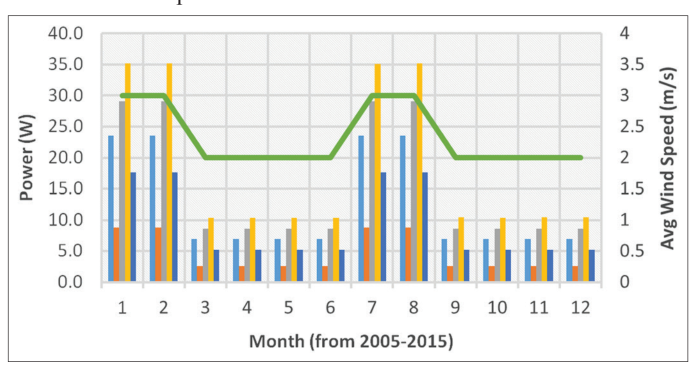
equator and experiences southwest monsoon starts from May/June till September and northeast monsoon starting from November till March. The northeast monsoon brings heavy rainfall to areas on the east side of Peninsular Malaysia Moreover, whereas the southwest monsoon wind is especially strong during this period, and usually brings heavy rain to the west side of Peninsular Malaysia.

There are five types of small wind turbine which have been considered in this paper. The technical details and characteristics of the SWT's are as shown in Table 3.

4. RESULTS AND DISCUSSION

Based on Table 2, there are six states which have relatively better potential of harvesting the wind power namely Johor, Kelantan,

Figure 2: Power generated by 5 type of small wind turbine and avg. wind speed at JHR-Johor Bahru from 2005-2015



Penang Sabah, and Terengganu. Figure 1 shows the power generated by five types of small wind turbine with respective color.

The bar charts in Figure 2-6 represents the power generated by the small wind turbine, and the line charts represent the power that can be extracted in an ideal theoretical case (Betz's Law). From equation (6), wind speed is the most affected parameter due to its power of cube. According to the equation, the rotor diameter is also one of the most important parameters, as the rotor diameter

Figure 3: Power generated by 5 type of small wind turbine and avg. wind speed at KTN-Kota Bahru from 2005-2015

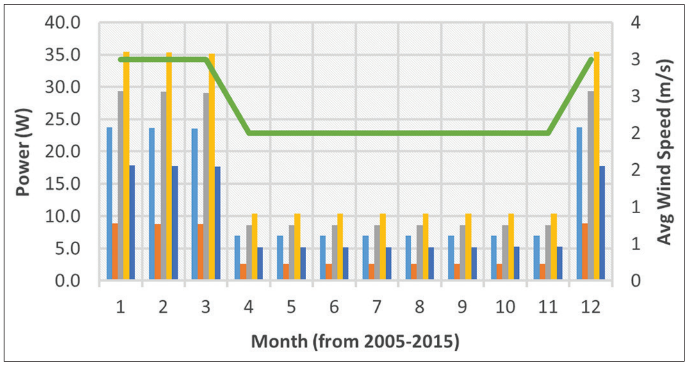


Figure 4: Power generated by 5 type of small wind turbine and avg. wind speed at TRG-Kuala Terengganu from 2005-2015

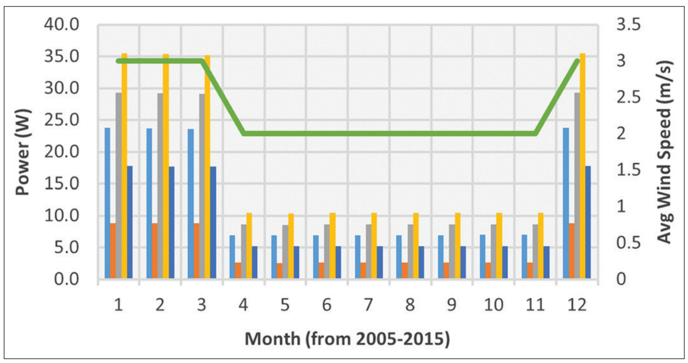


Figure 5: Power generated by 5 type of small wind turbine and avg. wind speed at PNG-George Town from 2005-2015

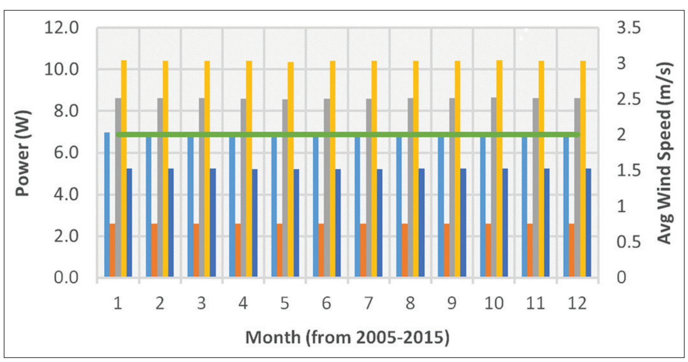
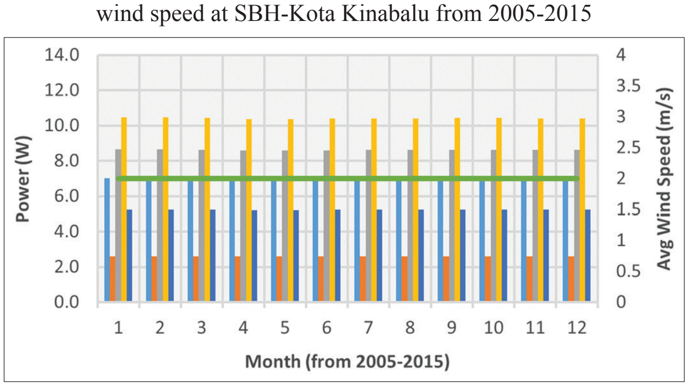


Figure 6: Power generated by 5 type of small wind turbine and avg. wind speed at SBH-Kota Kinabalu from 2005-2015



increase, the power that can be extracted from the wind turbine will increase significantly. The SWT2 generate the least energy due to its small swept area. The wind speed is much higher on May till September at Johor due to the Southwest monsoon. During this period, the wind is especially strong along with heavy rainfall. Having a 3m/s wind speed, the power that can be extracted will increase remarkably. Johor, which is located at the south of Malaysia have many areas close to coast, in which it may benefit the BTSs that are close to the coast. Kelantan is an agricultural state with many green paddy fields. According to standard roughness length table, the roughness class of this area is class 1 having roughness length of 0.03 meters. From Figure 3 and 4, the average wind speed at Kota Bahru and Kuala Terengganu are 3 m/s from December until April. The power that can be generated from the wind turbine having biggest swept area is SWT4. It can generate up to 30 W in theoretical cases. Both states are located at the northern side of the west Peninsular Malaysia, which the wind speed will be affected by Northeast Monsoon. Between April and November, the average wind speed at Terengganu and Kelantan are 2 m/s, which can generate not more than 15 W per day. In Penang, most of the lands that is covered by the sea is having an average wind speed of 2 m/s. The highest power that can be generated by the small wind turbines is SWT4 which has a larger rotor swept area.

Wind power generation depends heavily on the wind speed and the rotor diameter/swept area. Due to the equatorial climate, the air pressure and temperature experienced in low altitude areas are not significant. On the contrary, it will create a huge effect at high altitude areas. Through the analysis, the result shows that for all small wind turbine generating at 3 m/s wind speed can produce a large amount of power, and due to swept area, the results can be varied.

Based on the wind speed in Table 2, the data show that a certain area is far away from the weather station and may result in incorrect data. Apart from this, the height of the anemometer at the weather station is normally at a height 10 meters which may result in low wind speed. It is well established that the wind speed will increase as the altitude increase. However, the typical height of the Telco tower can range from 100 meters to 150 meters. Due to the large differences in height between anemometer and Telco tower, the results computed may be too conservative. Cut-in wind speed is another a factor that will affect the efficiency of the wind turbine. All five types of turbines that are used in this report has its specific cut-in wind speed.

5. CONCLUSION

Wind speed is a crucial factor to dictate whether enough power is available to be harvested to power up telecommunication sites. This paper has shown that based on the current available wind speed data which is measured at the height of 10 m, sole application of SWT is insufficient to meet the power demand of a typical telecommunication tower in Malaysia. However, it has been demonstrated that the SWT, especially vertical-axis SWT, can reduce the dependency on fossil fuel powered generators. Finally, the actual available wind power is expected to be significantly higher than the estimations in this study as it is expected for the wind speed to be significantly higher at the peak of the Telco tower compared to the current wind data at 10 m height.

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