STRUCTURAL EQUATION AND SYSTEM DYNAMIC MODEL OF ISLANDED WIND POWER GRIDS EVALUATION

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ABSTRACT

Recent advances in utilisation of renewable energy for power generation have boosted the development of renewable-energy market. Power generation using renewable energy gradually reduced carbon dioxide emission. Wind energy is one of the fast growing energy resources around the world. However, some assessments on the suitability of wind energy to be harnessed in Malaysia are needed before wind turbines can be established. In this research, a feasibility study of the utilisation of wind energy in Kudat has been conducted. Feasibility studies include the potential wind power site selection, wind speed prediction, wind turbine selection, economic and system assessment. A hybrid multi criteria decision making method with original values of the parameters has been introduced to identify the suitable location for wind power plant. In recent years, Malaysia is moving towards sustainable energy growth by giving tax exemption and financial supports to green energy developers. The economic assessment on the Malaysian government's policies has been carried out by using system dynamics analysis. System dynamics can perform holistic analysis from the planning until establishment of the project and generate the desirable scenario by changing the values of parameters. Wind speed prediction is one of the criteria for future power planning. Wind speed prediction in Kudat in 2010 has been investigated among three methods, which are Mycs-3, K-means clustering and Weibull analysis. Through the prediction of K-means clustering, the root mean square error is reduced 0.5% and more accurate if compared with Mycs-3. Besides, the financial planning of the wind power project based on Green Technology Financial Scheme (GTFS) 2010 was successfully developed. By using Vestas 3MW wind turbine as the study object, the return of investment is expected in between five to thirteen years. This is promising since the conventional power plant has typical ROI of ten years. In a nutshell, wind power plant is workable for the scenario in Malaysia.

ABSTRAK

Kemajuan penggunan tenaga boleh diperbaharui telah meningkatkan pembangunan pasaran tenaga hijau. Penjanaan kuasa elektrik dengan menggunakan tenaga hijau dapat mengurangkan pengeluaran karbon dioksida berbanding dengan loji jana kuasa konvensional. Tenaga angin merupakan salah satu daripada sumber tenaga hijau yang berkembang dengan kadar cepat di dunia. Walaubagaimanapun , penilaian terhadap kesesuaian penggunaan tenaga angin di Malaysia perlu dilaksanakan sebelum projek pemasangan turbin angin dapat dilancarkan. Dalam penyelidikan ini, kesesuaian penggunaan tenaga angin di Kudat telah dikaji. Kajian tersebut merangkumi penempatan loji jana kuasa tenaga angin, ramalan kelajuan angin, pemilihan turbin angin, analisa dari segi ekonomi dan secara kesuluruhannya. Kaedah menganalisi kriteria mod hibrid telah diperkenalkan dengan menggunakan nilai sebenar bagi menentukan tempat yang paling strategik untuk loji jana kuasa angin. Kebelakangan ini, Malaysia semakin maju ke era tenaga lestari dengan memberikan pengecualian cukai dan sokongan kewangan kepada pemaju-pemaju tenaga hijau. Kajian ekonomi dari segi polisi kerajaan Malaysia telah dijalankan dengan menggunakan analisis sistem dinamik. Sistem dinamik dapat menganalisis sesuatu projek secara keseluruhan dari permulaan sehingga peingkat akhir projek dengan memanipulasi nilai-nilai parameter kepada situasi yang dikehendaki. Ramalan kelajuan angin merupakan salah satu ciri bagi pengurusan tenaga jangka masa panjang. Ramalan kelajuan angin di Kudat pada tahun 2010 telah dikaji dengan menggunakan tiga cara, iaitu *Mycs-3*, *K-means clustering* dan *Weibull* analisis. Ramalan dengan menggunakan *K-means clustering* adalah lebih tepat dan menggurangkan *RMSE* sebanyak 0.5% jika berbanding dengan *Mycs-3*. Selain itu, pengurusan kewangan bagi projek tenaga angin berdasarkan GTFS 2010 telah dibangunkan. Vestas 3MW turbin angin telah dipilih sebagai objek kajian dan jangka masa pulangan pelaburan (ROI) adalah di antara lima hingga tiga belas tahun. Ini amat menggalakkan sedangkan ROI loji jana kuasa konvensional adalah sepuluh tahun. Secara keseluruhan, tenaga angin dapat digunakan di Malaysia.

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LIST OF SYMBOLS AND ABBREVIATIONS

EIA	-	Energy Information Administration
A	-	Cross Sectional Area
v	-	Wind Speed
ρ	-	Air Density
α	-	Wind Shear Exponent
C_p	-	Power Coefficient
SCADA	-	Supervisory Control and Data Acquisition
AHP	-	Analytical Hierarchy Process
MCDM	-	Multi Criteria Decision Making
TOPSIS	-	Technique for Order Preference by Similarity to Ideal Solution
USD	-	United States Dollar
CR	-	Consistency Ratio
RI	-	Random Index
CI	-	Consistency Index
PIS	-	Positive Ideal Solution
NIS	-	Negative Ideal Solution
SPSS	-	Statistical Package for Social Sciences
c	-	Weibull Scale Parameter (ms^{-1})
k	-	Shape Parameter (dimensionless)
σ	-	Standard Deviation
Γ	-	Gamma Function
CLD	-	Causal Loop Diagram
GDP	-	Gross Domestic Product
TNB	-	Tenaga Nasional Berhad
ROI	-	Return of Investment
P	-	Annual Payment (economic)
C	-	Net Cash Flow (economic)
GTFS	-	Green Technology Financial Scheme
GUI	-	Graphical User Interface
RMSE	-	Root Mean Square Error
VAWT	-	Vertical Axis Wind Turbine
HAWT	-	Horizontal Axis Wind Turbine
UTHM	-	Universiti Tun Hussein Onn Malaysia
$\dot{v}$	-	Volume Flow of Air
$\dot{m}$	-	Mass Flow
$\overline{V}$	-	Mean Wind Speed (ms^{-1})

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Renewable energy is the trend of the energy resource nowadays. It could be in the form of nature such as solar, wind, tidal, hydro, geothermal and so on. The energy is formed naturally and it can be harnessed as electricity and produce carbon dioxide free environment. In fact, the global warming issues are becoming more serious since last decades. Global warming brought climatic issues to the environment. Thus, the awareness of greener energy generation has encouraged the development of renewable energy. According to the U.S. Energy Information Administrative and U.S. Environmental Protection Agency [1, 2], carbon produced by renewable energy power plants is negligible because there is no fuel combustion during the process.

This chapter will further discuss the analysis of the carbon dioxide emission issues as well as the implementation of renewable energy in the world. Wind energy is emphasized in this thesis. The type of wind turbine and some wind energy conversion calculations are presented in this chapter. The problem statements and the objectives of research are also presented in this chapter.

1.2 Renewable Energy

Carbon dioxide emission is one of the reasons that causes global warming. According to the U.S. Energy Information Administration (EIA), the total carbon dioxide emission from the energy consumption in the world is 31780.36 million metric tons in 2010 [3]. Carbon dioxide emission in China is the most in the world follow by North America and United States. Meanwhile, out of 0.6% of the total carbon dioxide emission is from Malaysia. In order to reduce the amount of carbon dioxide emission, one of the solutions is to generate electricity by using carbon free resources. China and United States use renewable energy as a part of electricity generation in the country. From the data of EIA, the total renewable energy electricity generation for China and United States in 2010 is 770.92 Billion kWh (or 770.92 Tera watt hour) and 427.38 Billion kWh (or 427.38 Tera watt hour) respectively [3, 4]. In fact, Malaysia which is located at the equator has harnessed the renewable energy and generated 7.69 Billion kWh or equivalent to 6.5% from the total electricity generation in 2010 [5].

Apparently, electricity generation produces thousand million metric tons of the carbon dioxide. In order to minimise the impact of carbon dioxide towards global climate change, many countries consider renewable energies as the alternative electricity generation system. Various types of renewable energies can be harnessed. However, the availability of renewable energy in a particular country is crucial. The availability of resources is highly dependent on the geographical location of a country. Malaysia has the sun penetration throughout the year. Therefore, solar and wind power can be harnessed as an alternative power source. This is because whenever there is difference in temperature, wind will blow. Currently, Malaysia is utilising hydro power as the alternative power generation plant. From the global renewable energy status report as shown in Table 1.1, there is a trend towards the application of renewable energy [6].

Table 1.1: The global renewable energy status report

1.	Investment in new renewable capacity (Billion USD)	161	220	257
2.	Renewable power capacity (GW)	1170	1260	1360
3.	Hydropower capacity (GW)	915	945	970
4.	Solar PV capacity (GW)	23	40	70
5.	Concentrating solar thermal power (GW)	0.7	1.3	1.8
6.	Wind power capacity (GW)	159	198	238
7.	Solar hot water/ heat capacity (GW_{th})	153	182	232

1.3 Problem Statement

Malaysia is still at the early stage in utilisation of renewable energy as the energy resources. In order to encourage the private sectors and people in the nation to take part in the process of renewable energy development, Malaysia government has promoted the feed in tariff (FiT) policy. In the FiT, any individual or company who holds the FiT approval certificate from the authority can sell electricity which is produced by specified renewable resources to the distribution licensees. Currently, the FiT only benefits energy provider who is using either biomass, hydro, or solar as the energy resource. Obviously, wind energy market in Malaysia is not as mature as other countries. In fact, wind energy is considered as zero carbon dioxide emission and there are some places with considerable wind speeds for wind power generation in Malaysia. In this research, the feasibility of harnessing wind energy as alternative electricity generation is carried out. Preliminary procedures such as wind energy assessments in Malaysia have to be studied. The wind speed at interest sites should be evaluated before commencing the wind power project. The prediction of wind speed is necessary in order to obtain the estimated output power at the selected sites. Potential benefits of a wind power site can be retrieved by the manufacturer or project developers through the wind energy assessments.

Effective project management is the key of success to a new project which needs a lot of financial support and beneficial parties. Since Malaysia is not focused on wind power plant development so far, a well planned project in wind power project is essentially needed for commencing a wind power plant project. Project management can be enhanced by defining the criteria relationship that highly related to the project. Therefore, unnecessary expenditure can be avoided. This is very important to a developing country where more budgets can be allocated for others facilities, cultures, infrastructure, science, and technology development. By utilise renewable energy in Malaysia, the carbon dioxide emission can be reduced and giving contribution to a sustainable living country.

The interrelationship in between the parameters involve in a project development can affect the project's progress. There are many parameters involved and is a complex system analysis. Therefore, the methods recommended in this thesis are to curb the problem with wind power project development from the beginning till the end inclusive of cash flow analysis. From the analysis, the best circumstance could be foreseen by manipulating the values of parameters involved.

1.4 Objectives

Utilisation of wind power is considered a new alternative resource to Malaysia electricity generation. For this thesis, feasibility studies on the implementation of standalone wind power plant were investigated. The assessments are based on the objectives and scopes as follows:

1. To execute first assessment on wind farm site selection. Selection process is based on the multi criteria decision making (MCDM) methods. A novel approach which combined AHP and TOPSIS as an analysis tool is proposed.
2. To propose second assessment that is focused on wind speed prediction of the proposed wind site. The wind speed prediction is predicted by using two novel methods, which are Mycs-3 algorithm and K-means clustering wind analysis. In order to analyse the effectiveness of both methods, Weibull distribution is being used as the comparator.
3. To investigate third assessment on the feasibility of the project which involves financial planning, project development, project coordination, and also wind power site implementation. The interrelated criteria to establish a project is analysed by using system dynamic wind energy analysis.
4. To analyse on return of investment, the estimated power generation annually and the debt payment. This assessment is a financial planning section in the third assessment. With the simulated data, the decision maker on the investment could clearly review the wind energy market in Malaysia.
5. To study the feasibility of standalone onshore wind power plant inclusive of the investigation from three assessments.

1.5 Scope of Research

Wind energy is a broad topic which involves various types of analysis from planning stage to electricity generation. In this research, it is focused on the feasibility studies of utilisation of wind energy in Malaysia which is more on planning stage. The research scope is based on justifications as follows:

1. The Fit of wind power is not stated in the green energy development of Malaysia. Hence, the FiT scheme is not considered in this research.
2. The tax exemption issue is discussed in this research as it is covered by Green Technology Financial Scheme (GTFS) Malaysia. Therefore, the cash flow analysis of proposed wind power generation can be utilised by the local authority for ease of assessment.
3. The proposed wind farm site is based on independent service provider scheme instead of connection with national grid. This is because there are many agreement issues between local authority and service provider if intended to connect wind farm to national grid.

1.6 Contribution of the thesis

In this thesis, some novel approaches for the analysis of wind power project assessment and management are introduced and have been examined as follows:

1. A hybrid MCDM with the real values simulation ability is introduced. This approach combines two existing MCDM methods and establishes a better alternative selection based on the importance of the alternatives and criteria. The merits of both algorithms are utilised. Utilisation of hybrid MCDM method provides better decision making for a multi selection task.
2. The analysis of criteria and alternatives' priorities are presented in real value instead of user defined interest which currently available in the market. The advantage of the hybrid MCDM algorithm presented is the ability of handling both conditions. The time consumption to compute the criteria and alternatives' is gradually reduced.
3. The improved wind speed prediction method is derived to enhance the wind speed prediction for the potential wind farm. This is the advance version of the Mycielski algorithm. By appropriate adding the average difference for random number selection, Mycs-3 is proved to be more reliable in wind speed prediction. The predicted results are obsessed with the randomness nature of the wind speed without repetition faults.
4. K-means clustering wind analysis utilised the conventional k-means clustering algorithm and emerge as a new application in wind analysis. It gives a significant improvement in RMSE compares with existing wind speed prediction method.
5. A novel approach to analyse the wind power project in Malaysia is introduced. The approach is based on system dynamics analysis. The interrelated formulas are developed and the analysis is proven to be accurate in defining the economic model. System dynamics approach can analyse the

wind power project by manipulating the corresponding parameters. The analysis of the system can lead the user for economic efficient project.

1.7 Thesis Outline

This thesis identifies and proposes alternative solution for electricity generation in Malaysia from the point of view of technical wise and commercial wise. The literature studies of the relevant works are presented in Chapter 2. The literature studies of each proposed algorithm and methods are reviewed. Chapter 3 reviews the methods and approaches for the wind power implementation in Malaysia. Chapter 4 presents results and discussion for the proposed methods in the wind speed prediction. The month to month wind speed prediction is predicted and compared with the obtained result. The preferred prediction model is selected based on RMSE will also be presented in Chapter 4. Furthermore, the wind turbine selection based on predicted and obtained wind speed is also explained in Chapter 4. The contribution of system dynamics in wind feasibility studies in Malaysia is presented in Chapter 5. The conclusion and future works of the research are presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Wind Power

Wind is a natural resource that is available on the earth's atmosphere; a motion of air flows from high to low pressure. The pressure differences on the earth's regions due to the uneven heating by solar radiation make the wind blows. The equator is always heated by the sun throughout the year. Thus, the air temperature at the equator is higher than the poles. The changing of season might cause the wind to blow in different direction. For every moving object, it is associated with mechanical energy, so called kinetic energy. The content of energy in a moving object is dependent on its mass and speed. It can be defined as follows,

$$Energy = \frac{1}{2}(mass)(speed)^2 \qquad \text{(Nm)} \qquad (2.1)$$

However, the exact interest of harnessing the wind is by getting the power content in the wind. In this case, the volume flow of the air has to be determined. The volume flow of air, $\dot{V}$ is defined as a certain amount of air passing through a cross sectional area, A with the speed v. It can be simplified as the volume of air flowing through during a time. The relationship of volume flow, cross sectional area and speed is given by,

$$\dot{V} = vA \qquad (\text{m}^3\text{s}^{-1}) \qquad (2.2)$$

At the same time, the density, mass flow and volume flow of air can be described as,

$$\dot{m} = \rho\dot{V} \qquad (\text{kgs}^{-1}) \qquad (2.3)$$

Hence, the power density of the wind can be derived from Equation (2.1) and form the Equation (2.4). The derivation of the Equation is shown in Appendix A.

$$P = \frac{1}{2}\rho v^3 A \qquad \text{(W)} \qquad (2.4)$$

As from Equation (2.4), the power in the wind is directly proportional to the density of air, the cross sectional also known as the size of turbine and the cubic power of wind speed. It is clear to be seen that wind speed plays a very important role in determining the power output. Meanwhile, the air density is decreasing with increasing temperature and increase of the altitude above the sea level. The effect of temperature towards the air density is negligible, on one hand, and, on the other hand, the change of altitude might affect the air density significantly.

Wind shear is a phenomenon where wind speed is varying with the different height above the earth's surface. The wind might be slowed by the obstacles such as trees, grass, buildings and so on. Thus, at the higher level where the wind does not slow by the obstacles would have higher wind speed. It is found to be normal for an anemometer installed by the meteorology department would be the location that easy to access instead of at the desired wind turbine height. In the absence of actual wind data, the wind speed at higher level can be determined by wind profile power law as follows [7],

$$\frac{U_x}{U_r} = \left(\frac{Z_x}{Z_r}\right)^{\alpha} \tag{2.5}$$

where
U_x is the wind speed (ms^{-1}) at height Z_x
U_r denotes reference wind speed (ms^{-1}) at reference height Z_r
α is the wind shear exponent which has different values with different terrain characteristics as shown in Table 2.1.

Table 2.1: The wind shear exponent table

α value	Description	Roughness Class
0.10	Open water.	0
0.15	Smooth, level, grass covered terrain, open plain.	1
0.20	Row crops, low bushes with trees, countryside with farms	2
0.30	Heavy stand of trees, several buildings, hilly or mountainous terrain, village and low forest.	3

Since the approximate wind speed can be estimated, the mechanical energy that can be extracted from the air by the energy converter can be formulated. It is ideal to absorb all the power in the wind into the converter. However, this cannot be achieved practically. The wind after the converter, say v_2, will be zero if all the power has been absorbed. Thus, the turbine will not be moved if there is no wind after it. The situation of v_1, v_2, and the wind turbine can be illustrated in Figure 2.1. According to Betz limit, only 59.3% of the total power across the converter can be harnessed as electrical energy ideally. The power coefficient, c_p can be obtained by using the formula as follows,

$$c_p = \frac{1}{2}\left|1 - \left(\frac{v_2}{v_1}\right)^2\right| \times \left|1 + \frac{v_2}{v_1}\right| \tag{2.6}$$

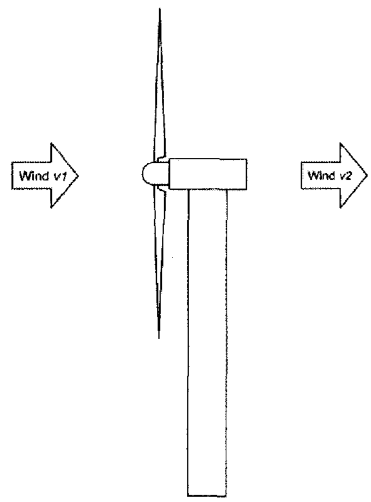


Figure 2.1: The situation of undisturbed wind, the wind turbine (converter) and the wind after wind turbine

The power coefficient is found to have the largest value, c_p=0.593 when $\frac{v_2}{v_1} = \frac{1}{3}$. The characteristic curve of power coefficient against the air velocity ratio can be illustrated in Figure 2.2 [7].

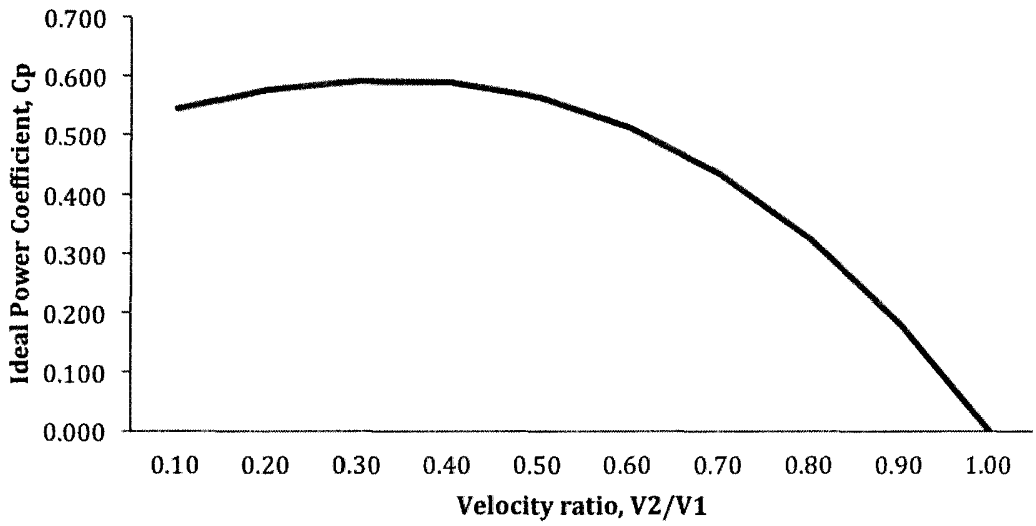


Figure 2.2: The graph of power coefficient against velocity ratio

In order to achieve the maximum of Betz' limit, the wind speed after the converter should be $\frac{1}{3}v_1$ ideally. It is equalled to $\frac{2}{3}$ of the undisturbed wind, v_1, will be retarded by the wind turbine and decrease to $\frac{1}{3}v_1$ after the rotor. However, this might be difficult to achieve due to aerodynamic and mechanical losses. With the latest wind turbine technology which can achieve 80% of the Betz' limit is considered a good design. Power of the wind that can be attained by the wind turbine can be expressed in Equation (2.7).

$$P = \frac{1}{2}\rho A v^3 c_p \tag{2.7}$$

2.2 Wind Turbine

Wind turbine has been successfully implemented for power generation since 1973 after the energy crisis [7]. There are two broad categories of wind turbine; horizontal axis wind turbine and vertical axis wind turbine. The major difference between these two types of wind turbine is the axis of rotation. Horizontal axis wind turbines can capture higher wind speed at higher level and therefore the fundamental support of the wind turbines must be strong. Meanwhile, vertical axis wind turbine can accept the wind in any direction, so called omnidirectional. The yaw system is not required in the vertical axis wind turbine. In addition, the components of the vertical axis wind turbine can be nearer to the ground, and this is much convenience for maintenance services. Since the installation of the vertical axis wind turbine is normally near to the ground, it tends to obtain lesser wind energy. This is because turbulence is higher at lower altitude, thus the wind speed is respectively slower. The types of wind turbines can be summarised in Figure 2.3.

Upwind turbine means the blades are facing to the direction of wind whereas the downwind turbine will encounter wind attacks at tower before reaches the rotor blades. Although the downwind turbines do not need the yaw system, the wind shadowing effect causes the flexing of blades and this contribute to the blade failure due to fatigue. Shadow effect is the disturbance of airflow caused by the tower and creates turbulence that affects the rotation of the rotor. In terms of production cost of wind turbine, the downwind turbine is cheaper than the upwind turbine due to lack of yaw mechanism. Wind power plant can be customised according to different requirements. The visualization of upwind and downwind turbine is shown in Figure 2.4.

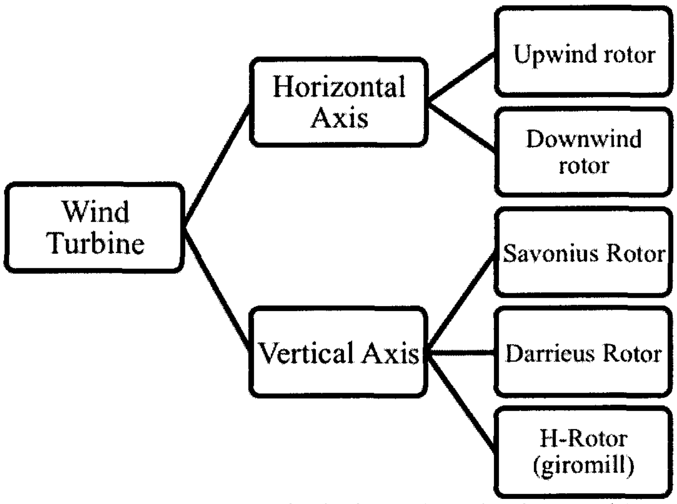
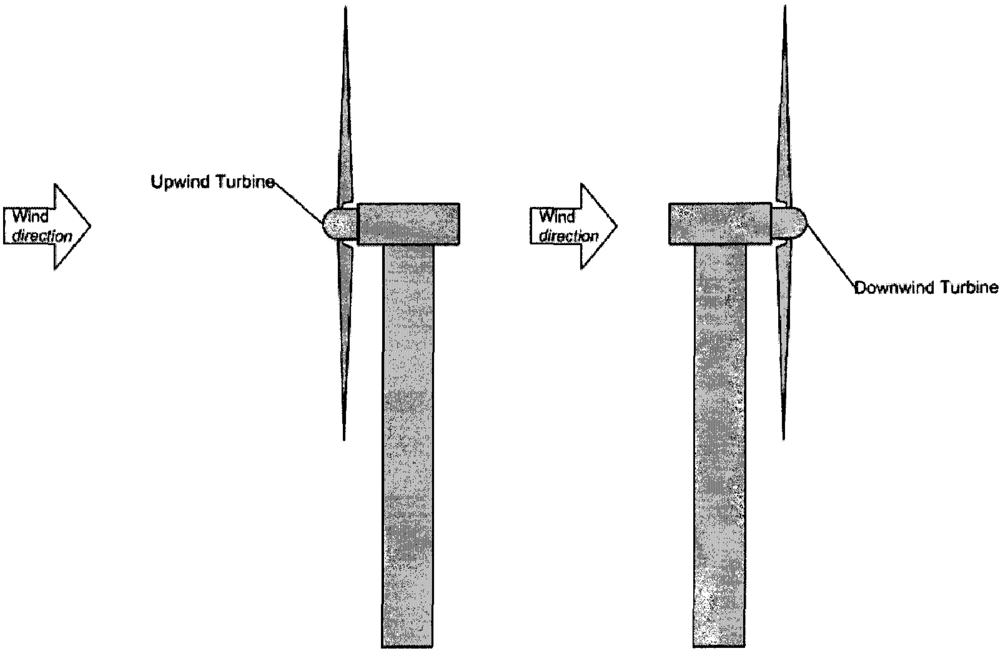


Figure 2.3: The type of wind turbines in the world



(a) (b)

Figure 2.4: The upwind (a) and downwind (b) wind turbines

2.3 Wind Power Implementation in Malaysia

Wind speed is one of the key factors that determined the potential power could be generated from a wind turbine. A wind resource map could be very helpful at the early stage of developing process. Throughout this research, the feasibility of wind power in Malaysia is emphasized. Some researchers have carried out assessments of wind energy potential in Malaysia. A group of researchers from Universiti Kebangsaan Malaysia analysed the wind energy potential in ten years for ten different stations in 1995 [8]. The outcome of the research was the data bank of wind patterns in the selected wind measurement stations in Peninsular of Malaysia, Sabah and Sarawak by using Weibull Distribution. Besides, the direction of wind blow had been tabulated in the paper. In 2011, a group of researchers from University of Malaya used Weibull distribution function to analyse the wind potential especially in Kudat and Labuan, which are located in Sabah, Malaysia [9]. The "WRPLOT" software is used to show the wind direction and the graphical illustrations of the results provide clearer presentations to the users [9]. The researchers claim that Kudat and Labuan are suitable for a small scale wind power plant. In addition, another research was done regarding the wind farm allocation in Malaysia by using multi criteria decision making method (MCDM) [10] and two locations were chosen as research target, namely Kota Bahru and Kudat. A literature reviews on wind energy studies in Malaysia are summarised as Table 2.2.

Table 2.2: Summary of wind energy analysis in Malaysia

Authors	Contribution	Methods & Parameter
K. Sopian, M. H. Y. Othman, A, Wirsat (1995)	Ten years wind speed analysis inclusive direction of wind blow in ten stations by using Weibull distribution.	- Weibull distribution. - Wind speed in Malaysia.
M. R. Islam, R. Saidur, N. A. Rahim (2011)	WRPLOT for wind speed and wind direction analysis in Kudat and Labuan. Recommend small scale wind power plant to establish in both sites.	- Wind speed analysis in Malaysia. - Weibull analysis. - Wind farm site selection.
H. H. Goh, S. W. Lee, B. C. Kok, S. L. Ng (2011)	Wind farm allocation based on multi criteria decision making method on Kota Bahru and Kudat. The results shown that Kudat is more suitable for wind power plant installation.	- Wind speed analysis in Malaysia. - Multi criteria decision making, AHP and Fuzzy AHP. - Wind farm site selection

2.4 Hybrid MCDM - Analytical Hierarchy Process (AHP)

The AHP approach is a powerful and flexible decision making process. It was developed by Dr. Thomas Saaty, a professor at the University of Pittsburgh [11]. It can be used either for the analysis or comparison among criteria. AHP is proven effectiveness in analyzing and comparing the quality of several telecommunications companies [12]. An evaluation was also made on alternate technologies in telecommunication.

On the other hand, Analytic Hierarchy Process is also popular in evaluation of undergraduate curriculum [13]. As an requirement of the evaluation, the affected parties (students, faculty, employers, etc.) are requested to evaluate the curriculum alternatives through internet web site [13]. Besides, the AHP approach is also used in solving management problem. For example, analysis of critical factors associated with successful implementation of WCM techniques in ISO 9001 certified firms were done based on AHP [14] . It is found that resistance to change is the most critical factor that leads to success of ISO 9001 implementation [14]. S. Yue, J. Yu, and B. Liang used a combination of data envelopment analysis (DEA) and AHP in their research based on assessment method of power system black-start effective schemes of ancillary services. By using the AHP approach, the best sequence of restoration path was obtained [15].

In the production line of a manufacturing company, the selection of machine tool must be done wisely. There are a lot of criteria need to be considered such as cost, profit, and period of modal returning. In order to make the best decision with given conditions, E. Cimren *et al.* used the AHP approach in machine tool selection [16]. The priority of alternatives can be changed from time to time. For example, one of the alternatives in machine tool named MX-50HB was ranked in the first place if cost analysis is the most prior for all the criteria. However, once the most prior criteria changed to reliability, machine tool named V-40 became the first among alternatives [16]. Thus, it is possible to make the final decision if the priority among cost and reliability could be identified clearly.

In the application of AHP associated with wind speed analysis, a wind farm allocation study in Malaysia was carried out [10]. Wind power density, terrain type, wind speed and noise restriction are treated as the criteria of analysis. The outcome of the research shows that wind power density of a potential site plays an important role in determining the location of wind farm.

2.5 Hybrid MDCM - Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is known as the "Technique for Order Preference by Similarity to Ideal Solution". This method is a unique technique to identify the ranking of all alternatives considered. In the TOPSIS method, the decision making matrix and weight vector are determined as crisp values and a positive ideal solution (PIS) and a negative ideal solution (NIS) are obtained [17]. In other words, PIS is a set of best value of criteria while NIS is a set of worst values of criteria. This method is applied to make wide-ranging evaluation of samples where it measured the distances between index value vector of each sample and ideal solution along with the negative ideal solution of the comprehensive evaluation [18].

Hwang and Yon [19] were first to introduce the TOPSIS method and they described the multiple decisions making as follow:
"*multiple decisions making is applied to preferable decision (such as assessment making priority and choice) between available classified alternatives over the multiple attributes or criteria.*"

It assumes that each criterion to be maximised or minimised. Therefore, the ideal positive and negative values of each criterion are identified, and each alternative judge against this information. It is noted that, in this typical multiple criteria decision making (MCDM) approaches, weights of attributes reflect the relative importance in decision making process. Each evaluation of criteria entails diverse opinions and meanings. Hence assumption that each evaluation of criterion is equally important is prohibited. [20].

TOPSIS method consists of two artificial alternatives hypothesis which are 'Ideal Alternative' and 'Negative Ideal Alternative'. 'Ideal Alternative' represents the best level of all attributes considered while the 'Negative Ideal Alternative' represented the worst attributes value. With these two hypotheses, sets of calculations using eigenvector, square rooting and summations are implemented to obtain a relative closeness value of the criteria tested. TOPSIS ranked the whole system by selecting the highest value of the relative closeness as the best attributes in the system.

From the literature studies of TOPSIS, it can be concluded that TOPSIS is capable to justify the suitability of a decision. Therefore, an analysis with justification of TOPSIS can enhance the decision in terms of numerical presentation. Due to there is no available wind energy project in Malaysia that can be referred, the proposed TOPSIS analysis can determine the wind site selection with firm justification.

2.6 Wind Prediction - Mycielski Algorithm

In order to build up a wind power plant, the initial site survey and the wind profile analysis of the potential site is compulsory. There are many solutions could be obtained from the relevant analysis. As an example, geographical information system (GIS) was used to generate the regional map of the wind potential site [21] . The physical condition could be analysed easily once the map is generated. This enabled project team members to discuss the strategy on the deployment of wind power plant based on the map for initial project management. Besides, the wind speed estimation on the potential site could determine the suitable wind turbine to be used. The location of the potential site could be changed if the wind speed estimated is not promising. Generalized Mapping Regressor (GMR) is the technique used by M. Beccali's [22]. GMR is an incremental self organizing neural network used to simulate the topography of a region. As a result, the map of average wind speed in the isle of Sicily, Italy was successfully created. The selected wind farm could be monitored easily with the aid of the supervisory control system stay connected with server from time to time.

Apart of that, the University of Athens used SKIRON modelling to forecast the wind speed for 5 days ahead [23]. Meanwhile, the Regional Atmospheric Modelling System (RAMS) has been developed at the Colorado State University and Mission Research Inc. ASTeR Division. RAMS can forecast wind speed in 48 hours later [24]. In addition, adaptive fuzzy neural network (F-NN) also applied for wind power prediction for 120 hours ahead [25]. However, these methods cannot handle the systematic errors which are caused by the local adaptation problems. The authors proposed Kalman filtering to improve the performance of the aforementioned methods. It is one of the statistical optimal sequential estimation procedures for dynamic systems. Results from the research show that systematic errors can be eliminated by using Kalman filtering.

In this research work, the prediction of wind speed is done by using the Mycielski algorithm. Mycielski approach is a data compression method which has been widely used in communication engineering and it is the advance version of the Limpel Ziv (LZ). This method fully utilises the historical data as a reference for the prediction value. The research on hourly wind speed prediction in Turkey was done by F.O. Hacaoglu *et. al* by using the Mycielski approach [26]. It is a new approach in wind speed prediction. The authors analysed and predicted the wind speed in Kayseri, Izmir and Antalya. The results of prediction were promising and very close to the actual data. The comparison of data fitting for both actual and predicted data was done by using the Weibull distribution function. Comparison in between actual and predicted data had proven the accuracy of the algorithm. In 2011, the same group of researchers modified the algorithm in order to solve the looping problem by adding random number into the predicted data [27]. The modified algorithm called as Mycielski-1 and Mycielski-2. In Mycielski-1, the random number which is between -0.4 to 0.4 is added into the predicted value. This random number can be changed according to the wind speed data. Meanwhile, the historical data were rounded to the nearest integer number and divided into a few cluster in Mycielski-2. The prediction is done by randomly select the historical data from different clusters. A comparison was also made between the modified Mycielski approach and the Markov chain.

Literature studies of Mycielski prediction had shown the capability to predict the wind speed in terms of monthly and yearly scale. However, the randomness of the wind speed is not defined in proper approach. Therefore, improvement on the random number selection is done in this thesis in order to maintain the randomness of wind speed.

2.7 Wind Prediction - K-means Clustering

K-mean clustering is one of the statistical data mining methods. The application of K-means clustering can be traced back to more than half century ago [28, 29]. The main idea of K-means clustering is to group sets of data into clusters. The data in each cluster can be analysed by using several approaches. Normally, this method is used in the application of image indexing [30, 31]. J. Cao *et al.* proposed an additional algorithm to overcome the "zero value" dilemma which would affect the efficiency of centroid selection in image recognition [30]. Besides, it is also widely used in system architectures [32, 33]. F. An and J. Mattausch proposed the combination of computer's hardware and the K-means software which could shorten the time of image segmentation process[32]. Results show that the time of execution is gradually reduced by using the proposed method. The time consumption for the algorithm is critical to pattern recognition technology. Hence, the improvement of the processing time of algorithm is the hot topic for the researchers [32, 34-36]. By shortening the processing time, the process will be more efficient. Meanwhile, G. Di Fatta *et al.* had implemented K-means algorithm in communication engineering. The clustering of the multimedia data could reduce the losses of messages [33]. There are also researchers using the clustering to analyse the protein interaction [37] and the natural environment [38].

The method of choosing the number of k in the algorithm is decisive that leads to appropriate analysis [31, 39]. It has become an argument of the k number selection since decades. The selection can be presented in different ways with different application. As an example, the k cluster in the prediction of velocities on motorways that had been done by J. Asamer and K. Din was by self selection [40]. In the particular paper, the cluster was divided into 4 clusters centre or also known as centroids. The reason of choosing 4 clusters is because the quantization error is reduced dramatically compared to others.

Besides that, K-means algorithm is applicable in prediction of software fault [41]. The Quad Tree method was added into the K-means algorithm to find the initial cluster. It was claimed that the combination of the algorithm would lead to a better prediction performance. There were many improvements done on the K-means clustering to overcome the drawbacks of the algorithm [34-36, 39, 42-49]. Most of the modifications were based on the initialization of the centroids. As stated in [39], the centroids of data would be inappropriate if the "out of boundary" data never been updated by the algorithm. The term of "dead unit" was describing this circumstance.

In the context of prediction, A. Kusiak and W. Li applied K-means clustering to predict the wind power produced by a wind turbine [50]. Five parameters have been investigated for the power prediction. The power produced is categorized into few clusters up to 1500kW for different wind speed. The performance of the prediction was then tested by using the mean absolute error (MAE), mean relative error (MRE), standard deviation of MAE and standard deviation of MRE [51].

The K-means clustering is effective on grouping up a series of data and analysis can be done based on the grouped centre data. On one hand, wind speed analysis consists of a series of wind speed database. On the other hand, wind speed can be categorised into effective group based on similar wind speed within a range of deviation. Therefore, K-means clustering is proposed to investigate the effectiveness of the said method in wind speed prediction.

2.8 Weibull Analysis for Wind Speed Prediction

Weibull distribution is commonly being used to describe the wind speed frequency distribution of a region. There are various types of Weibull distribution available. The differences of those types are the methods applied to estimate the Weibull parameters. The application of the Weibull distribution type is depend on the research requirements. Since decades ago, Weibull distribution was used in wind loads studies by Davenport [52]. Another group of researchers found that the Weibull distribution was useful and appropriate for the wind energy applications [53-55]. Justus *et al.* pointed out the advantages of five methods in Weibull distribution in wind energy application [53]. The five methods are as follow:

i) Least squares fit to observed distribution also known as graphic method [56].
ii) Median and quartile wind speeds.
iii) Mean wind speed and standard deviation also known as empirical method [57].
iv) Mean wind speed and fastest mile.
v) Trend of k *vs* $\overline{V}$.

As in the journal paper [53], Justus *et al.* commented that method (iv) and (v) are more simpler if compared with others. Besides, these methods also provided reasonable accurate representation to the actual wind speed frequency distribution.

Decades later, the comparisons of the Weibull parameter estimations was done by several researchers [56, 57]. S. A. Akdag and A. Dinler recommended power density method as the parameter estimation and the performance is compared with conventional methods [56]. On the other hand, T. P. Chang analysed six different types of the parameter estimation methods. From the result, Chang concluded that maximum likelihood, modified maximum likelihood and the moment method (empirical method) are more accurate compared to conventional parameter estimation [57].

There are few types of the parameter estimations applicable in different field of study [58-62]. In the research regarding wind energy, two-parameters Weibull function was used [63]. It is found that the maximum likelihood parameter estimation method in finding parameters is more suitable than the graphical method. In terms of wind speed analysis, the hourly wind speed prediction in Sicily by using Weibull distribution function was done [64]. Authors used the meteorology department's wind data to study on characteristics of wind speed at nine locations in Sicily. As a result, the suitability of the Weibull distribution function to the wind speed was clarified. Meanwhile, the previous research [9, 65, 66] also preferred two-parameters Weibull distribution to be the wind frequency analyser. On the other hand, the wind energy assessment in Malaysia was done by using the moment method [9]. Despite the diversity of parameter estimation, selection of estimation method should consider the availability of the data.

2.9 Application of System Dynamic

A well organized planning is the key of success for a project. The predictable wind speed is a decision factor that could encourage the commencement of a wind power project [67]. Due to this, the wind farm site has to be highly accessible by the wind. The analysis of economic return must be clarified in order to persuade investors in spending their money in the project.

On top of that, the risks of the project must be analysed in order to minimise the loss of revenue. Economic and technical risks play destructive roles in building up a project [68, 69]. The initial cost of running a project might be high. A 900kW wind turbine manufactured by Wind Inc. cost US $ 1.5 Million [70]. Hence, a strong financial management is necessary. Technical skills play important roles in the wind turbine installation and after sales services. A technical lifetime of a wind turbine is 20 years; sometimes faults like sensor problems, gearbox problem or even control system problem can occur due to wear and tear condition [7]. These are important factors that need to be considered before commencing a project. An overall analysis consists of inter related parameters is needed. By using the system dynamics analysis method, the interrelationship of criteria can easily be seen and analysed.

System dynamic is developed by Jay Forrester in year 1961. With the aid of computer simulation software, system dynamics can analyse the behaviour of a complex system by manipulating the parameters of a system from time to time. A system dynamics analysis consists of the whole picture of a system, the feedback loop of a system, the level and rate of change of the elements in a system. The process of building up a system dynamics model can be described as shown in Figure 2.5.

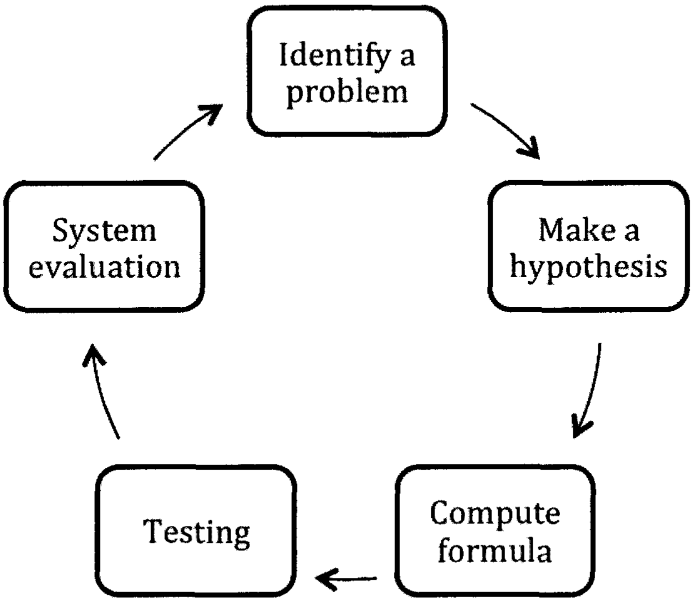


Figure 2.5: Process for system dynamics modelling

A causal relationship that indicates one element which affects the other is often used in system dynamics analysis. By using the causal loop diagram (CLD), the relationship between variables or parameters can be identified. Many researchers applied system dynamics in different field of studies. In order to analyse air passenger demand in an airport, system dynamic was used to investigate influences of parameters that could affect number of passenger [71]. The inter relationship of the criteria is clearly presented, and a flow diagram can easily explain the complicated system. Erik, Ann and Kim studied the service quality of restaurants that affect capital allocation [72]. By using CLD, it explained the gain and loss that might be encountered by a company due to the expansion of capital. The applications of system dynamics vary from decision making, software development, strategic planning, or even project management [73-80]. In this research, system dynamics is applied in wind power project management. The relationship in between the government policies, the fund allocation for renewable-energy project, energy demand, environmental impacts, topography and maintenance skills are studied. Figure 2.6 shows a basic CLD of power generation, energy demand, and number of wind turbines (resources) by using the simulation tool, VENSIM. In the Figure 2.6, the number of wind turbines can affect the total power generation. The polarity at the end of the arrow means that by raising the number of wind turbines can increase power generation. This loop is called reinforcing loop and represents as “R”. Meanwhile, “B” means balancing loop where the energy demand (consumption) will equalise the power generated.

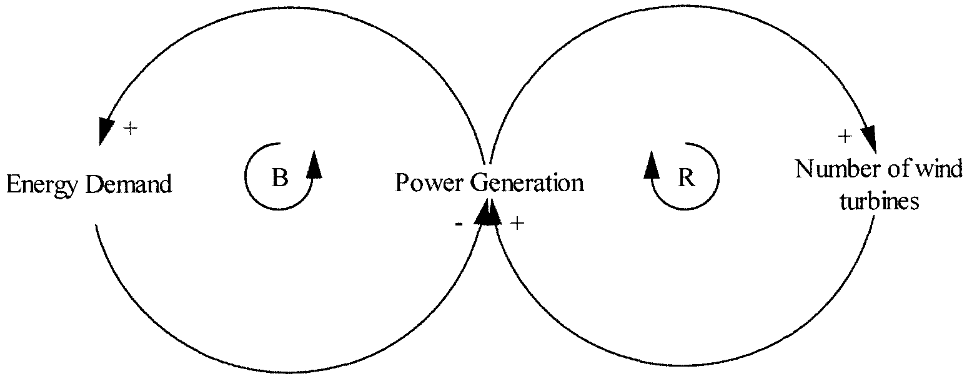


Figure 2.6: The causal loop diagram of power generation, energy demand and number of wind turbines

2.10 Summary

Literature reviews of several methods were done in this chapter. Implementations of these methods in wind power analysis by extracting the advantages of the methods are discussed in next chapter. The calculation and modification of each method is also presented Chapter 3.

CHAPTER 3

METHODOLOGY

3.1 Wind Site Selection and Wind Speed Prediction

Wind prediction is important for the wind power management. However, before proceed to the prediction process, a potential wind farm site need to be determined in order to save the unnecessary computation time. Two potential wind farm sites have been selected for the study. One is located at the east coastal area of Peninsular Malaysia, whereas the other is located in East Malaysia. Preferable wind site is chosen by using the hybrid multi criteria decision making method software based on few criteria. The wind speed of the chosen site will be used for wind speed prediction for further analysis. The predicted wind speed can be used to estimate the potential electricity generation by wind turbine. The wind speed data is the most important element in the wind speed prediction analysis. Some alterations of the wind speed data are done in order to suit the topography of the potential site. By using the altered data, the wind speed is predicted by using two methods, which are the Mycs-3 and K-means clustering methods.

3.1.1 Wind Site Selection

According to the wind speed data obtained from the Malaysian Meteorological Department, the anemometer at Kudat was placed at latitude 6°55'N and longitude 116°50'E at 10m from ground level. Meanwhile, the location of the anemometer at Kota Bahru is at latitude 6°10'N and longitude 102°17'E at 10m from ground level. The geographical location can be illustrated in Google Maps as shown in Figure 3.1.

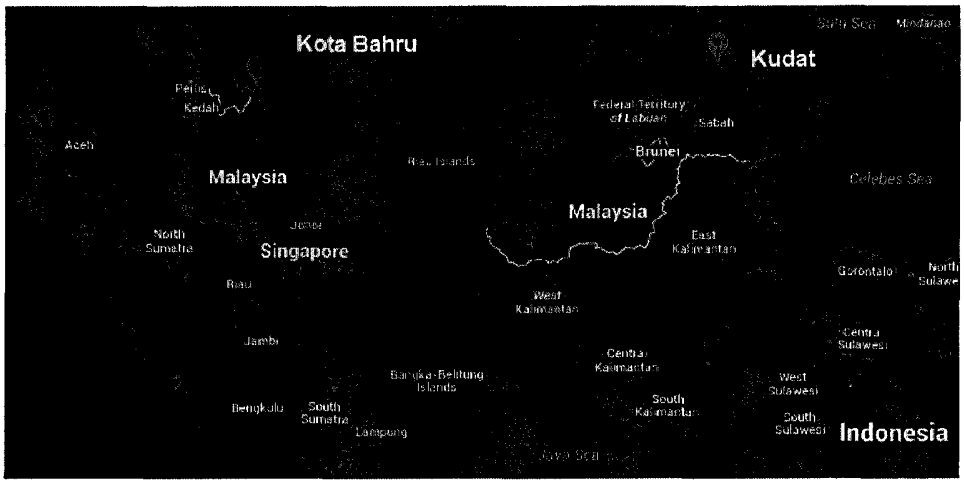


Figure 3.1: Location for anemometer at potential sites

These two locations were chosen due to considerable higher wind speed. The wind speeds for these two places were recorded at the local airport. According to the wind shear exponent value as tabulated in Table 2.1, the obtained wind speeds from both stations need to be altered to desirable height accordingly in order to satisfy the undisturbed condition. Normally, a horizontal wind-turbine hub is more than 50m high because there is less obstruction to harness the optimal volume of wind. There are numerous designs in hub heights. For this research, a Vestas manufactured V126-3.3MW wind turbine was chosen as the study object [81]. The hub height of the wind turbine as stated in the Vestas 3MW brochure is 126m. The value of U_x in Equation (2.5) is taken as 100m for average height. Meanwhile, the wind shear exponent value is dependent on the topography of the selected sites. The satellite views of both sites were captured from Google Maps with a scale of 1cm to 500m as shown in Figure 3.2 and Figure 3.3.

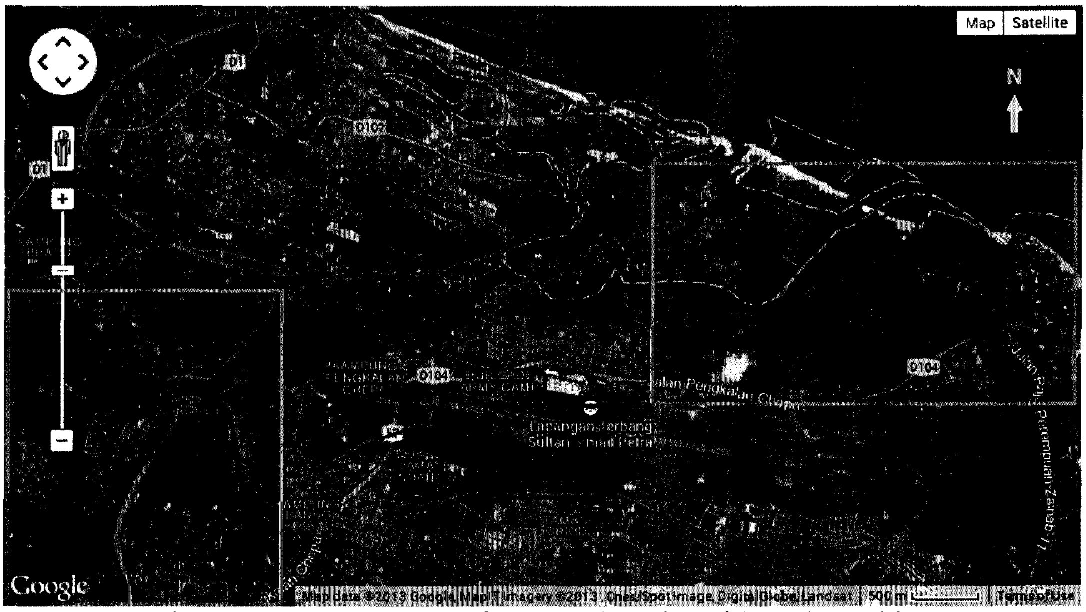


Figure 3.2: Topography of Kota Bahru site with scale 1:500m

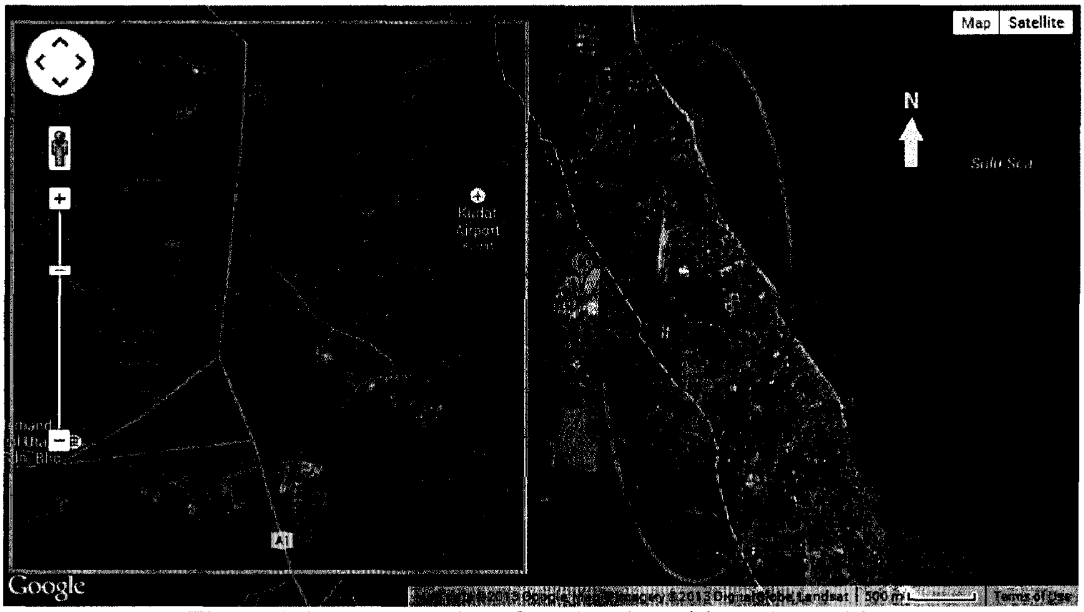


Figure 3.3: Topography of Kudat site with scale 1:500m

The ovals shape highlight show the village and the housing area of the local residents. Meanwhile, the squares shape highlight shown the forest area around the anemometer station. These village and forest area might obstruct the wind blow and weaken the strength of the wind. Hence, the wind shear exponent correspond to the roughness surface is used for wind speed calculation. From Table 2.1, the corresponding wind shear exponent for the village and forest terrain is 0.3. The wind speed of the potential sites should be altered with the wind shear exponent, α=0.3 respectively. The wind speed data of Kudat and Kota Bahru after the alteration of wind shear exponent is shown in Table 3.1and Table 3.2, respectively. An overview of the wind speed for both places is illustrated in graph plotted as in Figure 3.4 and Figure 3.5 respectively. The data size is 108 which is extracted from monthly wind speed of nine years.

Table 3.1: The wind speed of Kudat in ms^{-1} from 2002 to 2010

Month Year	JAN	FEB	MAC	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2002	9.6	7.1	5.7	4.1	2.5	3.0	5.0	5.7	3.6	3.4	2.7	6.1
2003	8.0	9.1	6.6	4.5	4.1	3.0	4.8	4.3	5.5	5.7	3.4	7.7
2004	9.6	6.4	4.8	4.3	4.3	6.6	4.1	5.9	2.7	5.9	3.0	4.1
2005	4.3	5.5	4.8	5.7	4.8	4.5	5.5	5.5	5.7	5.2	5.5	3.6
2006	5.9	7.7	5.2	5.0	4.8	4.8	4.8	5.9	5.2	6.1	4.8	5.2
2007	5.7	7.1	5.9	5.2	4.3	4.5	5.2	5.0	6.4	5.0	6.6	4.8
2008	5.7	5.9	4.8	4.5	5.7	4.3	5.0	4.1	5.7	4.3	4.1	4.5
2009	5.9	5.5	4.8	5.9	5.0	5.0	5.7	6.8	7.3	6.4	4.8	6.6
2010	7.1	7.7	6.8	5.7	5.0	4.5	4.3	5.5	4.5	5.5	4.3	4.5

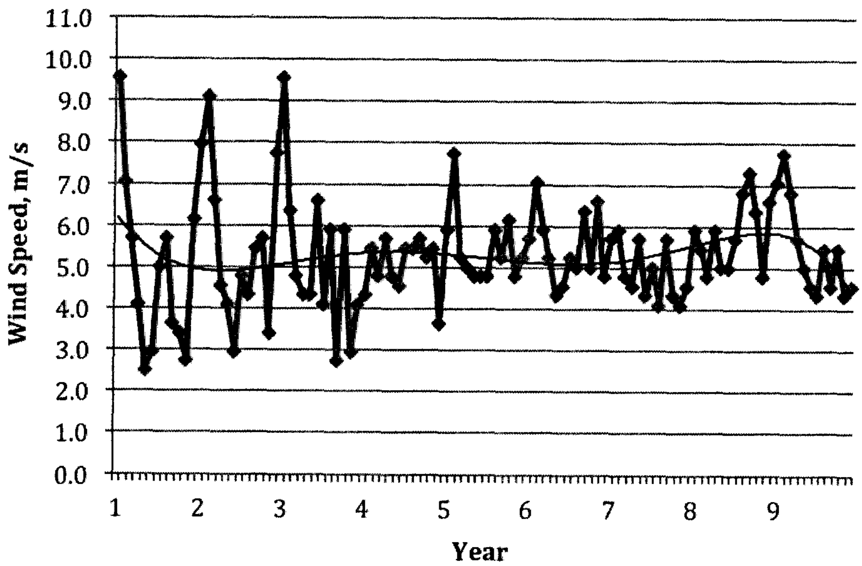


Figure 3.4: The distribution of wind speed in Kudat throughout nine years

Table 3.2: The wind speed of Kota Bahru in ms^{-1} from 2002 to 2010

Month / Year	JAN	FEB	MAC	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2002	7.2	5.8	5.4	5.0	4.2	4.0	4.2	4.0	3.8	3.6	3.2	5.4
2003	5.8	6.0	5.6	5.0	3.8	4.4	4.2	4.0	4.0	4.0	3.8	5.8
2004	7.4	6.4	6.4	5.0	4.2	3.8	4.2	4.0	4.4	4.2	4.2	5.6
2005	6.2	5.6	6.6	5.2	4.2	4.2	3.8	4.0	4.2	3.8	4.2	5.0
2006	5.2	7.2	4.8	4.2	4.0	3.8	3.8	4.0	4.0	3.6	3.4	5.0
2007	6.8	5.6	4.6	5.2	4.2	3.8	3.4	4.0	4.0	3.8	4.0	6.6
2008	5.2	6.4	6.8	4.4	3.4	3.8	4.2	4.2	3.8	4.0	3.0	4.2
2009	4.8	4.4	3.6	4.0	4.0	3.6	4.0	4.0	3.4	3.8	4.0	5.8
2010	5.2	5.0	5.0	4.4	4.2	3.8	3.8	3.4	3.6	3.4	3.6	4.2

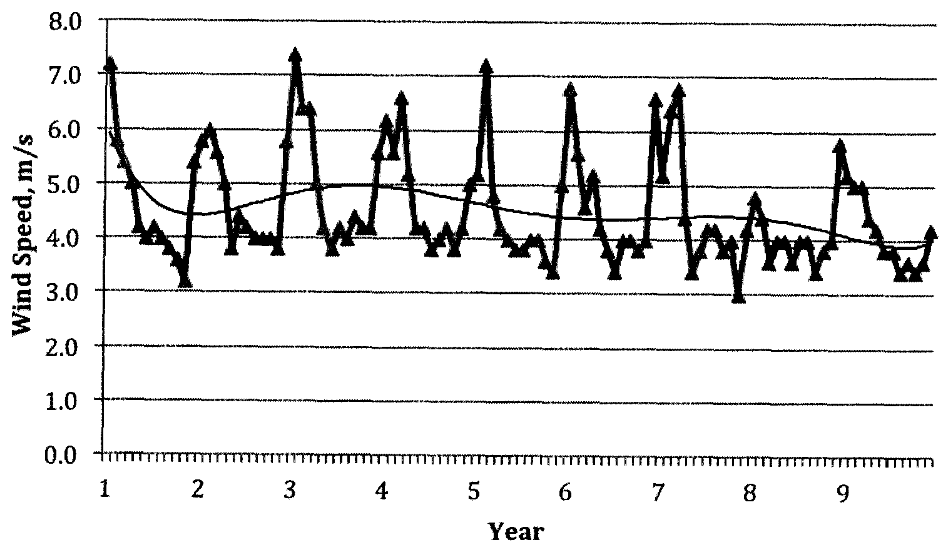


Figure 3.5: The distribution of wind speed in Kota Bahru throughout nine years

In order to select a suitable wind farm site out of the two potential locations, the hybrid multi criteria decision making method (hybrid MCDM) is used to justify the suitability of wind farm site. Basically, hybrid MCDM is a software consists of calculation that combines TOPSIS and AHP for the decision making. It also adapts the essences from TOPSIS and AHP to perform a better analysis. The hybrid MCDM mainly analyses the priority of the criteria for each alternative before involve in TOPSIS analysis. From the AHP algorithm, the calculation for the criteria priority can be fulfilled in three steps shown below.

AHP Step 1: Develop the weights of criteria.

a) Develop a single pair wise comparison matrix for the criteria. For this research, the ratio between criteria is obtained.

b) Multiplying the values in each row to obtain the n^{th} root of product and find the total root of product in the whole system.

$$n^{th}\ root\ of\ product = \sqrt[n]{product\ of\ each\ row} \tag{3.1}$$

where n is the positive integer number.

c) Normalizing the n^{th} root of product to get the appropriate weights.

$$weight = \frac{n^{th}\ root\ of\ product}{\sum(n^{th}\ root\ of\ product)} \tag{3.2}$$

d) Calculate the Consistency Ratio (CR) with the aid of Random Index (RI) and CR must be less than 0.1 to make sure the result is reliable. If CR exceeds 0.1, the adjustments of the pair wise values need to be done.

$$CR = \frac{CI}{RI} \tag{3.3}$$

$$CI = \frac{Lambda\_Max - n}{n-1} \tag{3.4}$$

$$Lambda\_Max = \sum(\sum column_{each\ alternative} \times weight_{per\ row}) \tag{3.5}$$

where $\sum column$ is the summation of pair wise values for each alternative vertically.

RI is a constant that is standardized for AHP analysis and the values are as in Table 3.3.

Table 3.3: The random index for AHP analysis

N	*RI*
1	*0*
2	*0*
3	*0.5*
4	*0.9*
5	*1.1*
6	*1.2*
7	*1.3*
8	*1.4*
9	*1.4*

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