Feasibility Study on Development of a Wind Turbine Energy Generation System for Community Requirements of Pulau Banggi Sabah

(Vote No. 77022)

A

Report

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In preparing this report, I was in constant contact with many people within the circle of experts and knowledgeable colleagues and people in the local authorities. They have contributed immensely towards the overall proposal of the so-called renewable hybrid power plant design. First and foremost, I would like to express my appreciation to the local authority of Kudat and the community of Pulau Banggi for their relentless effort in making the information made available and very accommodative to the research group from UTM.

I also wish to thank all the members of the UTM research team especially Prof. Nazri Jaafar, Assoc Prof. Dr. Omar Yaacob and Assoc Prof. Dr. Kamarul Baharin Tawi for their constant support, ideas and information during the overall implementation of this project from July 2008 till August 2009. Their views and constant criticisms have gone a long way in making the study useful for future implementation of the indigenously and locally developed hybrid energy system for rural community of Pulau Banggi

Abstract

Universiti Teknologi Malaysia (UTM) was invited to participate in the feasibility study of providing localised renewable energy system for Pulau Banggi in Sabah, in July 2008. Subsequently to this offer a four-man task force was formed consisting of lecturers and researchers from the Faculty of Mechanical Engineering (UTM) to undertake the project and to make recommendations of the possible renewable energy system for the requirements of a local community. Wind has been identified is the would be possible source but other renewable energies can also be considered in tandem, or as alternative to wind. Two site visits were made to Pulau Banggi within a span of six months from the commencement of the project. The visits were to gauge on the site, potential wind energy density, agricultural activities, demographic and other socio-economic development and requirements. Besides the visits, thorough data search and feedbacks from the local authority in Pulau Banggi and the local residents of the island were gathered. Wind data from researchers of UKM and USM were also used in the overall preparation of the proposed solution. Based on the current data the full blown wind farming on the island is not possible as average wind speed hardly hit 4 m/s on average – a critical and viable threshold value for investment on wind farming. The system proposed will be a small hybrid system having a capacity of 150 kW. The system is sufficient to support a maximum 150 households in a chosen site on the island. The hybrid system will consist of one or more of 9 m tall three-bladed horizontal type wind turbine (3 kW), a PV array of 20 kW and a generator set of 120 kW capacity. The estimated cost of the system is RM 700,000.00. This is based on the cost of producing the system alone locally at a unit cost of RM 4500.00 per kW. This is a modest figure which does not cover system integration work, labour, installation and others which can escalate to RM 900,000.00. The exploration on the use of bio-diesel fuels is an ideal proposition for the setting up of an environmental-friendly hybrid power generating system. In view of the agropolitan program for the remote island, where coconut and palm oil plantations are being proposed under the land redevelopment programme, the use of bio-fuel as a diesel extender will suit ideally to the concept of economical and environmental-friendly power generation system.

Abstrak

Universiti Teknologi Malaysia (UTM) telah di pelawa untuk menyertai di dalam kajian kesesuaian penggunaan sistem tenaga di perbaharui untuk Pulau Banggi di Sabah pada tahun 2008. Turutan dari pelawaan ini satu pasukan seramai empat orang telah di tubuhkan yang terdiri dari pensyarah dan penyelidik dari Fakulti Kejuruteraan Mekanikal (UTM) untuk menerajui projek ini serta membuat cadangan-cadangan tentang kesuaian projek sebegitu di laksanakan bagi memenuhi keperluan penduduk di sana. Angin telah di kenalpasti sebagai stu sumber yang sesuai tetapi punca lain juga di jangsa boleh di gunakan bersama udara atau gantian kepadanya. Dua lawatan tapak telah di laksanakan dalam tempoh enam bulan dari tarikh projek ini di mulakan. Lawatan tersebut adalah meninjau potensi ketumpatan udara, melihat dari dekat aktiviti-aktiviti pertanian, faktor struktur penduduk dan faktor sosio-ekonomi dan juga pembangunan setempat. Selain dari lawatan ini pengumpulan maklumat dari pihak berkuasa tempatan di Pulau Banggi dan juga penduduknya juga di kumpul. Data angin yang di kumpulkan oleh para penyelidik dari UKM dan USM juga di jadikan panduan di dalam menyiapkan cadangan keselurohan. Berdasarkan pada data yang terkumpul pembinaan sistem penjanaan tenaga berasaskan udara semata-mata adalah tidak sesuai di sebabkan halaju udara pada kadar purata 4m/saat adalah tidak boleh di capai – satu nilai yang kritikal yang membolehkan pelaburan di usahakan. Sistem yang di cadangkan adalah merupakan satu sistem hibrid yang mempunyai kuasa keluaran sebanyak 150 kW. Sistem sebegini adalah mencukupi untuk menampung keperluan 150 buah rumah perkampungan di pulau tersebut. Sistem hibrid ini akan terdiri dari satu atau lebih kincir angin tiga-bilah kipas (3 kW) setinggi 9 m, panel pengamatan cahaya matahari berkadar 20 kW dan satu janakuasa berkapasiti 120 kW. Anggaran kos bagi sistem yang di cadangkan ini adalah 700,000.00. Anggaran ini adalah berdasarkan kos penghasilan sistem ini secara tempatan dengan kadaran RM 4500.00 untuk setiap kW. Ini merupakan anggaran kasar yang tidak termasuk kerja-kerja integrasi, kos buroh, pemasangan dan lain-lain yang boleh mencecah sehingga RM 900,000.00. Kajian penggunaan bahanapi biodisel dalam sistem ini merupakan satu lagi langkah yang baik didalam mengzahirkan satu sistem hibrid penjanaan tenaga yang mempunyai ciri-ciri mesra alam sepenuhnya. Seiring dengan terlaksananya program Agropolitan di pulau tersebut, di mana tanaman kelapa dan kepala sawit sedang di terokai, maka penggunaan bahanapi sebagai satu kaedah menjimatkan bahanapi disel dapat menyumbangkan kepada satu cadangan pembangunan sistem hibrid yang mesra alam secara menyeluroh.

Table of Contents

Chapter 1: Introduction

1.1 UTM's Involvement

The undertaking by UTM to implement a study on the potential of harnessing electric power generation from wind to complement the needs of residents of Pulau Banggi was first mooted in March 2008. During a technology showcase event in Bayan Lepas, Penang, in which the automotive development centre (ADC) of UTM was asked to demonstrate an alternative fuel technology program for the then Prime Minister, YAB Dato Sri Abdullah Badawi has lead to the idea of UTM to undertake the study. He was asked to test drive a demonstration car, which was a Proton Waja fitted with a gaseous fuel system using ethylene. The Prime Minister had test-drive the car and was impressed with the perfromance and the technology produced. Subsequently, YAB Dato Sri Abdullah Ahmad Badawi has requested UTM to look into the possibility of introducing a technology solution for the requirement of the islanders of Pulau Banggi, of which he has made a visit a few days earlier, prior to attending to the UTM technology showcase in Dewan Millenium in his constituency of Kepala Batas, Penang.

The vice chancellor of UTM then, YB Tan Sri Prof. Ir. Dr. Mohd Zulkifli Tan Sri Ghazali, immediately took up the idea and had instructed the same group frot ADC to take up the challenge in undertaking thestudy and eventually make a proposal of the would-be system for the island. A series of meetings were held in UTM and at the Ministry of Rural Development (*Kementerian Pembangunan Luar Bandar*) in Putrajaya on several initiatives. Among them was a plan visit to the island, not only for the UTM task force to conduct a feasibility study but also for other agencies such as SIRIM, TNB, FELDA and FELCRA to get involved.

The first visit was made in early July 2008 in which the team consist of YB Tan Sri Zulkifli, Prof. Azhar Abdul Aziz of ADC, Prof. Nazri Jaafar of Aeronautical Dept UTM and En. Wan Zaidi Wan Omar, a staf who was a postgraduate student whose research topics centered on the wind turbine system. The first visit was made on the 7th of July 2008 to the island with visits to the small enclave of Karakit, a primary school, a low-cost housing programme for the hadcore poor, a water treatment plant and the would-be site for the construction on the hybrid energy system, which on an elevated ground in the centre of the island. Karakit is 24 km from the port of Kudat. The group also were taken to a fishing village facing the Palawan Sea to view the condition of the fishing community whose life is very basic and in dire need of some forms of infrastructure. The briefing was made by a JKR officer and few local personnel of the department on the island. This is a one day tour and it is a rather tiring trip in consideration that the ferry ride from Kudat is almost a two hour ride while the island visit was a six hour. The distance to Kudat from Kota Kinabalu is a 340 km journey.

The second visit was made in 21st September 2008 and this time around the mission was to gather additional information pertaining to the actual site for installation, to visit the TNB pilot station on solar hybrid powerplant (a 650 kW energy station), and to assess the logistic for the future construction of UTM's own station and to visit the locality in which wave energy could be one of the alternative solution for UTM's eventual proposal. This time around the visit was made by Prof. Azhar Abdul Aziz, Assoc. Prof. Dr. Omar Yaakob of Marine technology Department and Assoc. Prof. Dr. Kamarul Baharin Tawi of the Automotive Engineering Depratment. The idea of wave energy initiative was proposed by a group of researchers from the marine technology department who wish to ride in tandem the OTEC (ocean technology) solution with possibly wind turbine and diesel generator as package for an energy solution if not for the whole island then for a communal use of say 100 to 300 kW requirement.

1.2 Workscope

The idea of setting up a pilot windmill project initiative was perhaps to study the potential of wind power for isolated communities of the island. Upon completion of these two site visits, the group has agreed to undertake the following tasks to come up with the initial proposal:

- i) wind map data gathering by putting up a wind vane mini station in a primary school (sekolah kebangsaan Pulau Aur) on the island.
- ii) Assessment on the energy requirement of the island.
- iii) Proposal for the setting up of either a stand alone or a hybrid energy mini plant which will possibly encompassing wind and biomass sources.

1.3 Task Force

The task force to undertake the mission comprised of:

- i) Prof Ir. Dr. Azhar Abdul Aziz
- ii) Prof. Dr. Nazri Jaafar
- iii) Assoc. Prof. Dr. Omar Yaacob
- iv) Wan Zaidi Wan Omar

The four researchers were supported by the technicians and facilities from the Automotive Development Centre (ADC) and the Aeronautical Laboratory of Faculty of Mechanical Engineering. They were tasked to implement the study for a period of two years.

1.4 Limitations

Perhaps the most challenging task to overcome is the logistical problem in view of the distance the task force need to travel from UTM to the island. Secondly is the unavailability of data, especially wind data and topography of the remote island. Thirdly is the constrained (approximately RM 260,000.00) budget which does not warrant the team to have much room to play with. Finally is the time frame (two years) which is rather tight to undertake feasibility study, design and development of a working wind energy farming system of its kind in the island of Pulau Banggi.

Chapter 2: Agropolitan Development Concept

2.1 What is Agropolitan Programme?

The Agropolitan Programmes was the Malaysian Government initiative to eradicate poverty in Malaysia. Agropolitan projects throughout Malaysia was initiated under “Program Lonjakan Mega Luar Bandar” (PLMLB) Scheme; one of high impact programs in Malaysia; supervised by Land and Regional Development Unit, MRRD. Originally, the Agropolitan projects were initiated under a government body from the Prime Minister Department (PMD) which was known as NITF (National Implementation Task Force). During the time (2006/2007), 44,000 absolute poor were identified all over Malaysia; including Peninsular Malaysia, Sabah, and Sarawak [1]. Four ministries including MRRD have been given a mandate to overcome the problems. MRRD was responsible to eradicate 10,000 absolute poor. At the same time, the government has initiated another project known as The Malaysian Corridors (Northern, East Coast, Southern or locally known as “Iskandar”, Sabah and Sarawak) mainly made to enhance the socioeconomic level of local community. Regarding this, from 10,000 absolute poor that MRRD responsible, 4,400 absolute poor were given to the Corridors and the remaining 5,600 absolute poor were MRRD responsibility. Proposals for Agropolitan projects were prepared by the related agencies under the ministry.

The Ministry of Rural and Regional Development and the National Implementation Directorate are the backbone of this project. The project was then implemented by Land and Regional Development Unit, Ministry of Rural and Regional Development with an appointed organizer, Rubber Industry Smallholder Development Authority. Close relationship between the planner, implementer, organizer, and also the project participants would develop a power to strengthen the project and success in the future.

Doubtlessly agriculture can be the main medium for poverty eradication. Similarly, agriculture has the ability to overcome employment problems and enhance the community socio-economic level. Malaysia is one of the countries that gain benefits from agriculture. Hence, in order to ensure that agriculture will continue to benefit this country, a number of high impact agricultural programs have been initiated; the programs are TKPM (Permanent Food Production Parks), HIP-ZIA (High Impact Project-Aquaculture Industrial Zone), and Agropolitan.

2.2 Pulau Banggi as the Beneficiary of the Agropolitan Programme

Felcra Berhad, the federal land rehabilitation agency, will develop 10,000 acres (4,166ha) of government land on Pulau Banggi in northern Sabah for a rubber plantation. Pulau Banggi is the largest island in Malaysia. It will invest "hundreds of millions of ringgit" in the project to be carried out jointly with the state government. The first phase of the project bagin in January 2009 and involve construction of infrastructural facilities. Pulau Banggi has been left far behind the mainstream of development. The implementation of the Agripolitan project is to transform the current activities from sea-based economic activities to land-based activities with phase two of Pulau Banggi Agropolitan Project near completion. Of the 1,100ha of land earmarked in this phase, 980ha have been cleared and are ready for planting. The initial phase of the project, launched in 2007 is to eradicate hardcore poverty, involved 700ha of rubber plantation.

Pulau Banggi was officially declared a district in 1975 but the island of 14,000 people and 43 villages had a dubious distinction as 75% of its population lived below the poverty line.The majority of the population are from the *Ubian* ethnic group. There are also *Dusun Banggi, Kegayan, Suluk* and *Bajau* living here. Previously the island dwellers were dependent on fishing and subsistence farming but they have since begun rubber cultivation, working with Felcra Bhd, the agency entrusted with the first agropolitan project on the island. The islanders are seeing light at the end of the tunnel with the advent of tarred roads, clean water and electricity [2].

Figure 2.1: Jetty of Pulau Banggi.

Figure 2.2: View from a vantage point where potential wind gust is known to occur in Pulau Banggi.

Figure 2.3: The delapitated state of infrastructure in Pulau Banggi.

A solar hybrid system costing RM21mil (150 kW rating) was constructed at the centre of the island that brings electricity supply to villagers in seven areas and eliminated the need for generators that were restricted to the Karakit town fronting the jetty and could only provide electricity up to 12 hours a day. The major contractor for this work is TNB. Meanwhile, a network of 36km of pipes to provide clean water to eight villages was also laid by the Sabah Utility company.

The Agropolitan Project in Pulau Banggi is worth RM 167.36 million in which the funding comes from the Federal government. The funding is for the construction of a jetty, offshore fishing activity, human capital development, upgrading of rural roads, rural electrification and water treatment plant.

Felcra is the lead agency entrusted to undertake the development programme of the island. It is to develop two specific areas within the island i.e. the estate of Ladang Sejahtera Lok Tohok with a land area of 4,500 hectare dan the Banggi Plantation

(8,000 hectare) for the hardcore poor population of the island. Each of the participants will be given a parcel of land of 4 hectares to work on the plantation rubber.

Other than agriculture and fishery, the island will be turn into eco-tourism activity focussing on the conservation of the rainforest and improve the infrastructure on a few waterfall spots within the island. Pulau Banggi has been the launching pad for the mega agriculture transformation initiative launched by the then Prime Minister in 2009. This initiative to the imitigate hardcore poverty among the rural community in remote area of Sabah.

2.3 Summary

The Agropolitan project has a lot of potentials for the society especially the absolute poor community. The development of Agropolitan projects throughout Malaysia was an acknowledgement from the Malaysian government that rural, poor, and so called neglected people has their own power to uplift their socio-economic level as well as increasing their quality of life. The improvement of the program in the future Agropolitan projects can be the main catalyst to overcome the absolute poor problem in Malaysia. The agropolitan projects in the peninsula were now bearing fruit as the participants' income had increased from RM200 a month to between RM1,000 and RM1,300 monthly. Their condition of living need to be improved by providing the basic needs of modern society.

Chapter 3: Pulau Banggi: Demographic and Energy Requirements

3.1 Demographic

Pulau Banggi is one of the island worth visiting in Kudat region. It is part of a group of islands located within the Kudat region and is off the northern coast of Sabah in Malaysian Borneo. With an area of 440.7km square, it is the largest island in Malaysia followed by the islands of Langkawi and Penang. The area around Pulau Banggi has the second largest concentration of coral reefs in Malaysia and contains an important mix of habitats including mangroves, seagrasses and open sea providing safe haven for endangered animals such as turtles and the dugong.

The Sabah State Government has proposed Pulau Banggi, along with neighboring Pulau Balambangan, Pulau Malawali, Pulau Balak and Pulau Molleangan amongst others, for gazettement as the Tun Mustafa Park under the jurisdiction of Sabah Parks. This Kudat-Banggi conservation area forms the southern half of the Balabic Straights which separate Borneo from the Philippines and is the meeting place of the Sulu and the South China Seas. The Tun Mustafa Park being over 1 million hectares will be the biggest marine protected area in Southeast Asia.

To reach the main town of Karakit on Pulau Banggi there are daily one hour ferry services that depart from the northern fishing town of Kudat. Kudat is a three hour drive from Kota Kinabalu – the state capital of Sabah, Malaysia.

Diving around Pulau Banggi is astounding and bursting with diversity, due to its proximity to the Balabic Straight Corridor the currents can provide more than a challenge. The corridor serves as a passageway for marine life forms from plankton to whalesharks and all the creatures in between such as dolphins, various species of sharks and whales, turtles, and shoals of oceanic fishes. Dive sites are encased in a stunning variety of corals such as gorgorian fans, bubble coral, staghorn, lettuce corals and many other hard and soft corals. Making their home in the corals are batfish, squid, shrimp, eels, nudibranchs and countless other creatures. There are several merchant ship wrecks in the area, two of which lay in 20-25m of water, and another that is laying at 50m. There are records of countless others just waiting to be discovered.

Thick virgin rainforest covers more than 70% of Pulau Banggi which is largely unaffected by development, and gorgeous white sand beaches wrap around most of the coastline. Over 17,000 people of various ethnicity call Pulau Banggi home. The main town on Pulau Banggi is the town of Karakit; here you will find the Bonggi Resort on the waterfront. They have basic rooms with fan and shared bathroom, or you can go a step up with air-con and attached bathroom. For the more adventurous, Banggi-style wooden huts are available and those who are both adventurous with no fear of heights can opt for the tree houses that present beautiful views of the sea and surrounding islands.

Banggi remains relatively under-developed, and coastal households are considerably below the Sabah monthly poverty line income of RM 700 [3]. Fishing, on which these communities continue to depend heavily on for food and income, accounts for about 70% of the island's economic activity. The population growth rate in Banggi is approximately 4.4% per year, which is substantially higher than the 2003 national rate of 1.6% [4]. North Sabah's proximity to the Philippine border has attracted many illegal immigrants to Kudat and Banggi, many of whom are fishers, and thus increase the pressure on coastal fisheries resources. In fact, illegal transient fishers are estimated to make up 28% of the total fisher population in the Sulu–Sulawesi Marine Ecoregion (SSME) area of Sabah, which consists of the northern and eastern parts of Sabah that are bounded by the Sulu and Sulawesi Seas (including Banggi). In 1999, roughly 17% of Banggi's residents were believed to be illegal immigrants [5].

Figure 3.1: Map of Sabah showing Pulau Banggi is the biggest island ofshore in the Kudat Division.

3.2 Energy Scenario

Power shortage is rampent in Sabah and the outage effects the economic activities in many parts of Sabah especially in the north and the east coast of the state.Current capacity of electricity in Sabah now is approximately close to 1000 MW. The forecast demand growth of electricity is in a region of 7.7% per annum. A fully integrated grid connecting the West Coast Grid to the East Coast Grid was completed on 28 July 2007, and about 80% of the customers are now connected to this integrated grid. Currently the cost of subsidised electricity in Sabah is 33 sen per kWhr. Less reliable system in the East Coast & rural areas having higher frequency of interruptions. Major powerplant is badly needed in the east coast of Sabah. About 25%-50% of East Coast demand is supported by West Coast Grid. The energy option available for Sabah are coal, oil, hydro, biomass, solar, wind, fuel cell and geothermal. For remote requirements the electricity is met by the use of small isolated systems, mainly diesel generator sets which are mainly powered by diesel.

Potential power from palm oil mill biomass after deducting competitive uses of EFB and on-going projects is 256MW.However, mesocarp fibre and palm kernel shell are currently being used to generate steam for POM process. Therefore, only EFB is available to be considered as a fuel source and taking into account the 50% non-energy uses of EFB, potential power to be generated is around 70MW.

Potential of geothermal energy was discovered through a study carried out by Jabatan Mineral & Geosainsvia magneto telluric study in 2007 located in AppasKiri, Tawau. The initial survey identified a reservoir of 2000~3000m depth with 220~236ºC temperature, which will provide an estimated potential capacity of 67MW. This study is at its early stage, the second phase study on *isotope study*will be conducted under 10thMP to achieve a more credible results. The project can be categorized as cost effective, environmental friendly and reliable, despite its initial high capital investment.

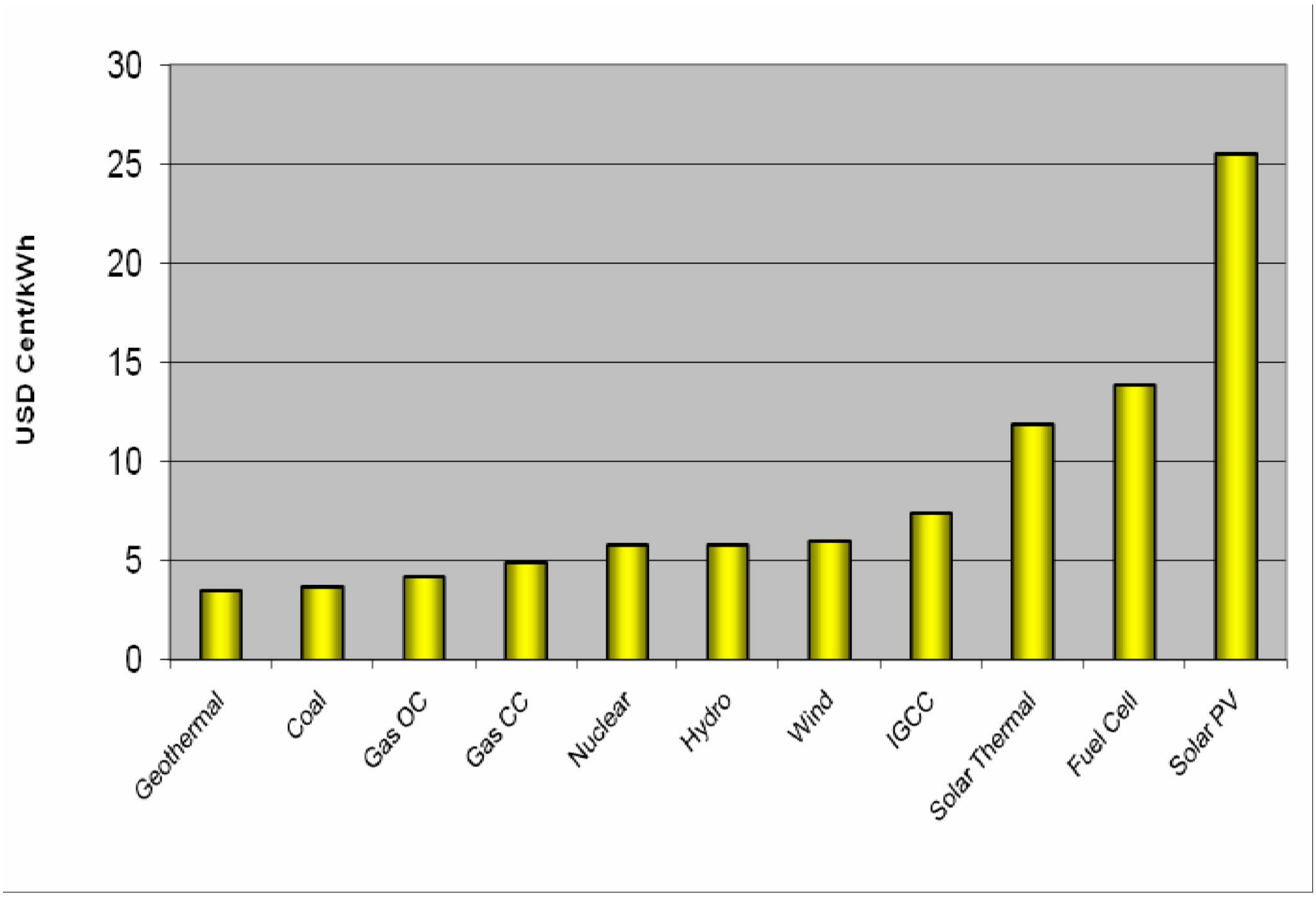


Figure 3.2: generation cost per kWhr for Sabah [6].

For solar energy usage two demonstration programmes were implemented i.e. in Kalabakan and Pulau Banggi respectively. Both are rated at 150 kW and they operated in Tandem with diesel generator sets. From the studies made it was noted that for a 1MW capacity solar system it requires a space of 6 acres of land equivalent which equals to 3 football field. Judging from this constrain, it will not be a wise option for Sabah due to its logistic and cost of installation, operation and maintenance.

Sabah Electricity Sdn. Bhd. (SESB) is the leading proponent of Small Renewal Energy Program in the country. SESB is currently implementing renewable energy initiative of 30 MW capacity representing 3% of Sabah electricity needs. It will continue to play major role in encouraging such RE initiatives, in line with the national ‘Five-Fuel’ policy which also aim to minimise the impact of power generation on environment.

Beyond 2015, the Sabah ‘Five-fuel strategy’ will focus on gas (75%), Coal (10%), hydro (7%), renewable energy (5%) and oil (3%).To meet Sabah socio-economic and infrastructure development. The economic competitiveness of the nation requires low cost, reliable electric power.The most technically and economically feasible option is a COAL FIRED PLANT that meets the stringent DOE and World Bank requirements.SESB will continue to pursue Renewable Energy as an integral part of its energy option and thus meeting the government five- fuel policy [6].

3.3 Wind Speed Statistics in Malaysia

Malaysia is situated in the equatorial region of South East Asia approximately between Latitude 1^{o}N and 7^{o}N and Longitude 100^{o}E and 119^{o}E and Malaysia experiences humid tropical climate with warm and uniform temperature, high humidity and high rainfall, adequate sunshine and light winds. The weather is influence by two monsoons namely the northeast monsoon from November to March and the south west monsoon from May to September. These two monsoons are separated by two short inter-monsoon periods.

Is it possible to harness the wind energy on a large-scale basis to generate electricity in Malaysia? Malaysia's mean annual wind speed is low at no more than 2 m/s. Nonetheless, the wind does not blow uniformly throughout Malaysia; wind speed varies according to region and month.

Malaysia experiences two main weather seasons: southwest monsoon (May/June to September) and northeast monsoon (November to March). Wind speeds during the southwest monsoon are often below 7 m/s, but during the northeast monsoon, wind speeds could reach up to 15 m/s particularly in the east coast of Peninsular Malaysia. Moreover, during April to September, the effects from typhoons striking neighbouring countries (such as Philippines) may cause strong winds (even exceeding 10 m/s) to Sabah and Sarawak. Pulau Banggi is said to experience this phenomena on intermittent basis [7].

So although Malaysia, as a whole, experiences low wind speeds, some areas in this country see strong winds during certain periods of the year.

The highest annual average wind speed ever recorded is 3 m/s in Mersing in the state of Johore. The diurnal wind speed is between 2 m/s (at 9.00 am) to 3.9 m/s (at 3.00pm). The highest average monthly wind speed is 4.2 m/s recorded in the month of January. The average wind speed is also very low in the highlands as recorded in Cameron Highlands at 2 m/s. That is in general the wind speed is too low, far below the minimum speed of 12 metres per second for the generation of energy [8]. It is shown by the wind turbine installations in Pulau Perhentian (in state of Trengganu) and Pulau Banggi (in the state of Sabah). However, there is a possible wind energy potential for small wind turbines operating at below wind speed of 3 m/s during the monsoon season from November to March the islands and areas facing the South China Sea in the East coast of Peninsular Malaysia and the in the Kudat regions of Sabahin which Pulau Banggi is situated.

3.4 Global Scenario of Harnessing Wind Energy

According to the World Wind Energy Association, wind energy is in a boom cycle. As a new global high-tech sector, more countries are taking advantage of this untapped source of renewable energy. In 2005, the total worldwide capacity reached nearly 60,000 MW with 11,300 MW installed in 2005 and expectations to double the capacity by 2010. Overall wind energy contributes only 1% of global electricity generation, but some countries and regions are already producing up to 20%. Wind energy growth in Asia is on the rise. Both India and China are leading the switch to wind with more installed capacity and manufacturing facilities. India ranks fourth (4,400 MW) and China moved from tenth position to number eight with 1,260 MW. The Asian region is set to be the most dynamic geographical zone with a growth rate of 48%.

In Malaysia, wind energy conversion is a serious consideration. The potential for wind energy generation in Malaysia depends on the availability of the wind resource that varies with location. Understanding the site-specific nature of wind is a crucial step in planning a wind energy project. Detailed knowledge of wind on-site is needed to estimate the performance of a wind energy project. This first requires a general assessment of the wind energy potential nationwide.

As reported by a 2005 University Kebangsaan Malaysia study, the use of a 150 kW wind turbine in the Terumbu Layang Layang demonstrated with some success [9]. However, the availability of wind resource varies with location. It is necessary to first carry out a general assessment of the wind energy potential nationwide. This can then be followed with detailed assessment in promising locations. These assessments must be completed before further action can be decided on. Understanding the wind resource is a crucial step in planning a wind energy project. Detailed knowledge of the wind at a site is needed to estimate the performance of a wind energy project. Wind energy is considered a green power technology because it has only minor impacts on the environment. Wind energy plants produce no air pollutants or greenhouse gases. However, any means of energy production impacts the environment in some way, and wind energy is no different.

Wind energy conversion systems have great potential in tourist resort islands. However, wind energy assessment studies nation wide has to be studied. Various institutions of higher learning and research institutions have conducted research and development in the field of renewable energy. Funding for research and development in this field of renewable energy should be allocated with the objectives of solving fundamental problems and product development.

3.5 Estimating Wind Energy Potential for Malaysia

Malaysia experiences two main weather seasons which is the southwest monsoon (mid May - September) and the northeast monsoon (November - March). Wind speeds during the southwest monsoon are generally below 7 m/s, but during the northeast monsoon, wind speeds can register up to 15 m/s, particularly in the east coast of Peninsular Malaysia. Moreover, during April to September, the effects from typhoons striking neighbouring countries (Vietnam and Philippines) may cause strong winds (in excess of 10 m/s) to Sabah and Sarawak.

Even though Malaysia, as a whole, experiences low wind speeds, in some areas facing the South China will experient strong winds during certain periods of the year. The research group requested an overall wind speed data for several towns all over Malaysia from the Malaysian Department of Meteorology. These data were from 1989 to 2008 (20 years), and in addition to them From the analyses made, Malaysia experiences stronger winds in the early and late parts of the year. On the whole, Malaysia’s mean annual wind speed is 1.8 m/s. However, towns in the east coast of Peninsular Malaysia such as Mersing, Kota Baharu, and Kuala Terengganu experience stronger winds. For these places, their mean monthly wind speed could exceed 3 m/s. East Malaysian towns, Kota Kinabalu and Labuan (with the exception of Kuching) also see stronger wind speeds than the national average.

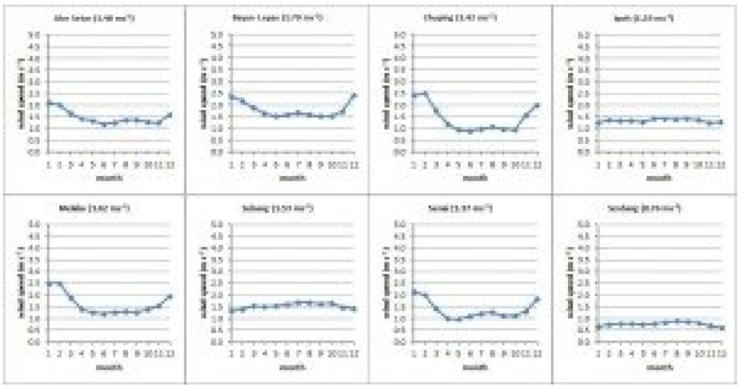


Figure 3.3: Mean monthly wind speed for several towns in Malaysia, 1989-2008.

Mean annual wind speed of a given town in brackets (1 of 2).

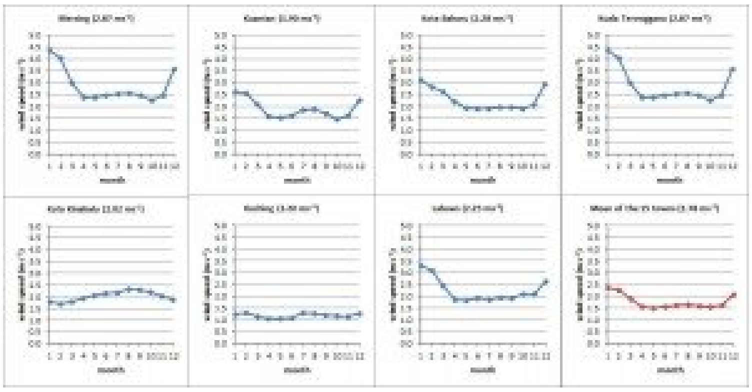


Figure 3.4: Mean monthly wind speed for several towns in Malaysia, 1989-2008.

Mean annual wind speed of a given town in brackets (2 of 2).

The assumption here is to round up the mean wind speed of Malaysia to 2 m/s. This is the national average of wind speed which is at 2 m height above ground. Roughly, doubling the height increases wind speed by 10%. Since a typical wind turbine is 32 m above ground, this means the average wind speed at the height of 32 m above ground will be nearly 3 m/s.

The energy per square meter area of a wind turbine is determined as:

0.5 x air density (kg per cubic meter) x wind speed x wind speed x wind speed.

Note that wind speed (m/s) is cubed (multiplied by itself three times). Using the above equation and assuming air density as 1.3 kg per cubic meter and mean wind speed as 3 m/s give the energy per square meter area of a wind turbine as 17.55 W.

The diameter (d) of a typical wind turbine is 25 m, so the circular area of a wind turbine is:

3.142 x 0.25 x d x d = 491 square meter.

Hence, the total power generated from a single windmill is:

17.55 W per square meter x 491 square meter = 8,617 W.

It is important to note that the efficiency of windmills is not 100% but typically only about 50%. This means the actual total power generated from a single windmill (*i.e.*, after correcting for inefficiency) is half of 8,617 W or 4,309 W.

Now let's determine the power that could be generated from a square meter of land area occupied by windmills. Windmills cannot be placed too closely to each other. Doing so would cause one windmill to slow down the wind speed for another windmill. But placing windmills too far from each other wastes land area. Typically, windmills are placed no less than five times their turbine diameter without losing power. Hence, the power that could be generated by windmills per unit land area is

power per windmill (W) / land area per windmill (square meter)

or

4,309 W / [(5 x 25 m) x (5 x 25 m)] = 0.28 W per square meter land area.

Recall that the diameter of a typical wind turbine is 25 m and two adjacent windmills are placed apart by five times their turbine diameter.

Windmills typically require a minimum wind speed of between 3 to 5 m/s to generate electricity. This means there would be periods of too low wind speeds for the windmills to generate electricity. Periods in a day with enough wind speed for the windmills to generate electricity is called “load factor” or “capacity factor”. So, what is the load factor for windmills in Malaysia on the whole?

In calm weather, the typical wind speed distribution in a day can be depicted as below.

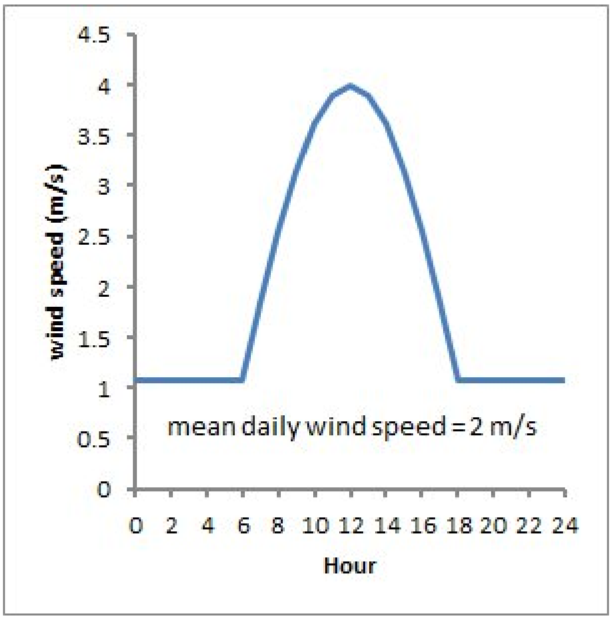


Figure 3.5: Idealized daily wind speed distribution in Malaysia.

Wind speed is higher during the day (from sunrise to sunset) than that during periods before sunrise and after sunset. Wind speed follows a sine curve during the day, and it remains constant for periods before sunrise and after sunset. I am going to roughly estimate Malaysia’s load factor by assuming that maximum wind speed is twice the daily average wind speed and that the average wind speed during the day is also twice that during early morning and night.

Consequently, the period when wind speed exceeds 3 m/s, which is required for windmills to generate electricity, is calculated to be from 8:45 to 17:15 hours. This is a duration of 6.5 hours or a load factor of 27% where windmills are able to harness the wind for electricity generation.

Thus, the power that could be generated by windmills per unit land area is 27% of 0.28W, which is 0.0756 W per square meter land area or 1.8 Wh of electricity generated per square meter land area per day.

Malaysia’s demand in electricity by 2020 is expected to reach 124,677 GWh, so if wind power is to meet, say, 10% of this projected electricity use, the total land area of Malaysia needed for windmills is:

(124,677 x 1000 x 1000 x 1000 x 0.1) /(1.8 x 365) = 18,977 square kilometer.

This area is equivalent to 6% of the total land area of Malaysia, or equivalent to over 1.2 million windmills to be set up.

Currently, it cost about RM1 for every 1 W of electricity generated from wind energy in Malaysia. Thus, to meet 10% of Malaysia’s electricity demand in 2020 would cost approximately RM1.4 billion to setup the required number of windmills. These figures so far show it is plausible to harness the wind energy for electricity generation in Malaysia.

Although the minimum wind speed required for windmills is between 3 to 5 m/s, the minimum wind speed for commercial viability is instead 7 m/s. None of the 15 towns which were analyzed had mean monthly wind speeds exceeding even 5 m/s.

According to *Tenaga Nasional* between 500 to 2000 MW worth of electricity could be generated from wind energy in Malaysia (meeting between 3.5 to 14% of the expected demand in electricity by 2020) [10] . They further reported there are areas such as the Malaysian-Thailand border which see wind speeds up to 15 m/s.

It is interesting to note that wind energy suffers contrasting problems with solar energy. Technology for solar energy is prohibitively expensive for large scale use in Malaysia. In contrast, harnessing wind energy is much cheaper than that for solar energy to set up in this country. Malaysia enjoys plenty of sunshine (as much as 3 kWh per square meter) all year round, but Malaysia sees only low wind speeds and sees high winds only at certain times of the year.

Chapter 4: Wind Turbine Design

4.1 Introduction

A successful wind turbine design is based upon a number of calculations and considerations. From load considerations to the development of control systems, there are many specifications that can decide the efficiency of the final wind turbine design. The following discussion should help you learn about every aspect associated with the design of a wind turbine.

4.1.1 Load Calculations

A wind turbine design must is based upon the consideration of the turbine's strength to withstand extreme winds and high-speed winds. The design of wind blades contribute significantly towards this. Long and narrow blades are considered for modern day turbine designs. Moreover, the number of blades is limited to two or three, as more number of blades can lead to larger force exerted on turbine.

4.1.2 Structural Dynamics

A wind turbine is subject to fluctuating winds and thus, varying amount of forces is applied on it. Thus, an important consideration for wind turbine design is to analyze the forces that would be responsible for bending and stretching various components of the turbine. In addition, the individual as well as joint vibrations of different components need to be calculated in advance. All these things are studied as the structural dynamics for a turbine.

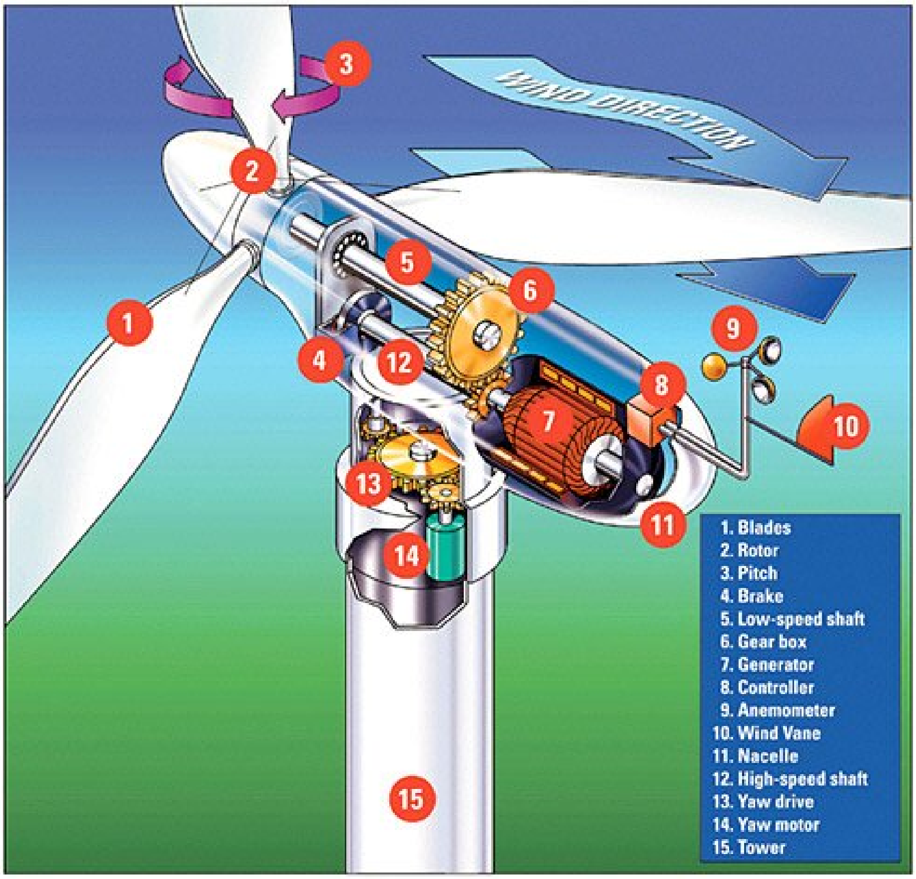


Figure 4.1: Components of a wind turbine [11].

4.1.3 Power Control

Power control is important for a wind turbine design to protect a turbine against damage during wind blows at higher than rated speed. Stall control and pitch control are two useful methods in this direction.

4.1.4 Wind Blade Design

The design of blades attached with the rotor also contributes towards an effective wind turbine design. Apart from the shape and weight of these blades, it is also important to consider the material used for manufacturing them. As far as number of blades is concerned, two or three-blade wind turbines are the most popular ones in the industry.

4.1.5 Temperature Considerations

The wind turbine design has an important consideration in the form of temperature operating limits. It is an important aspect to consider, especially when the machine is to be installed in a low temperature area. For example, in cold climatic conditions, internal heaters are integrated with turbines to protect them against low temperature and snow.

4.1.6 Control Systems

Yaw control system is an important part of the wind turbine design, as it helps in minimizing non-symmetrical loads and increasing power output. Electrical braking and mechanical braking are other control systems to perform various tasks.

Certification and testing of wind turbines is done before their installation to ensure that a good wind turbine design contribute towards production of energy.

4.1.7 Size of Turbine

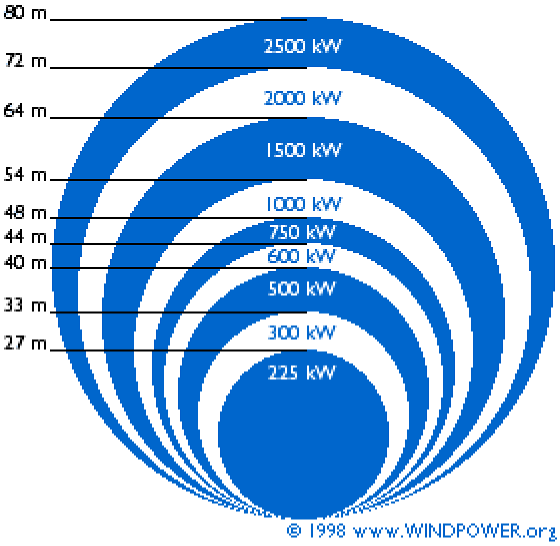


Figure 4.2: Size of turbine [12].

The area of the disc covered by the rotor, (and wind speeds, of course), determines how much energy can be harvested in a year.

Figure 4.5 illustrates the scenario of the normal rotor sizes of wind turbines: A typical turbine with a 600 kW electrical generator will typically have a rotor diameter of some 44 metres. If you double the rotor diameter, you get an area which is four times larger (two squared). This means that you also get four times as much power output from the rotor.

Rotor diameters may vary somewhat from the figures given above, because many manufacturers optimise their machines to local wind conditions: A larger generator, of course, requires more power (i.e. strong winds) to turn at all. So if you install a wind turbine in a low wind area you will actually maximise annual output by using a fairly smallgenerator for a given rotor size (or a larger rotor size for a given generator) For a 600 kW machine rotor diameters may vary from 39 to 48 m. The reason why you may get more output from a relatively smaller generator in a low wind area is that the turbine will be running more hours during the year.

Reasons for choosing large turbines

1. There are economies of scale in wind turbines, i.e. larger machines are usually able to deliver electricity at a lower cost than smaller machines. The reason is that the cost of foundations, road building, electrical grid connection, plus a number of components in the turbine (the electronic control system etc.), are somewhat independent of the size of the machine.
2. Larger machines are particularly well suited for offshore wind power. The cost of foundations does not rise in proportion to the size of the machine, and maintenance costs are largely independent of the size of the machine.
3. In areas where it is difficult to find sites for more than a single turbine, a large turbine with a tall tower uses the existing wind resource more efficiently.

Reasons for choosing smaller turbines

1. The local electrical grid may be too weak to handle the electricity output from a large machine. This may be the case in remote parts of the electrical grid with low population density and little electricity consumption in the area.

2. There is less fluctuation in the electricity output from a wind park consisting of a number of smaller machines, since wind fluctuations occur randomly, and therefore tend to cancel out. Again, smaller machines may be an advantage in a weak electrical grid.
3. The cost of using large cranes, and building a road strong enough to carry the turbine components may make smaller machines more economic in some areas.
4. Several smaller machines spread the risk in case of temporary machine failure, e.g. due to lightning strikes.
5. aesthetical landscape considerations may sometimes dictate the use of smaller machines. Large machines, however, will usually have a much lower rotational speed, which means that one large machine really does not attract as much attention as many small, fast moving rotors.

4.1.8 Roughness and Wind Shear

High above ground level, at a height of about 1000 m, the wind is hardly influenced by the surface of the earth at all. In the lower layers of the atmosphere, however, wind speeds are affected by the friction against the surface of the earth. In the wind industry one distinguishes between the roughness of the terrain, the influence from obstacles, and the influence from the terrain contours, which is also called the orography of the area.

In general, the more pronounced the roughness of the earth's surface, the more the wind will be slowed down. Forests and large cities obviously slow the wind down considerably, while concrete runways in airports will only slow the wind down a little. Water surfaces are even smoother than concrete runways, and will have even less influence on the wind, while long grass and shrubs and bushes will slow the wind down considerably.

In the wind industry, people usually refer to roughness classes or roughness lengths, when they evaluate wind conditions in a landscape. A high roughness class of 3 to 4 refers to landscapes with many trees and buildings, while a sea surface is in roughness class 0. Concrete runways in airports are in roughness class 0.5. The same applies to the flat, open landscape to the left which has been grazed by sheep. The term roughness length is really the distance above ground level where the wind speed theoretically should be zero.

The wind speed at a certain height above ground level is:

$v = v_{ref} \ln(z/z_0)/\ln(z_{ref}/z_0)$

v = wind speed at height z above ground level.

v_{ref} = reference speed, i.e. a wind speed we already know at height z_{ref}. ln(...) is the natural logarithm function.

z = height above ground level for the desired velocity, v.

z_0 = roughness length in the current wind direction.

z_{ref} = reference height, i.e. the height where we know the exact wind speed v_{ref}.

In the above example, it is assumed that the wind is blowing at 7.7 m/s at 20 m height. We wish to know the wind speed at 60 m height. If the roughness length is 0.1 m, then

$v_{ref} = 7.7$

$z = 60$

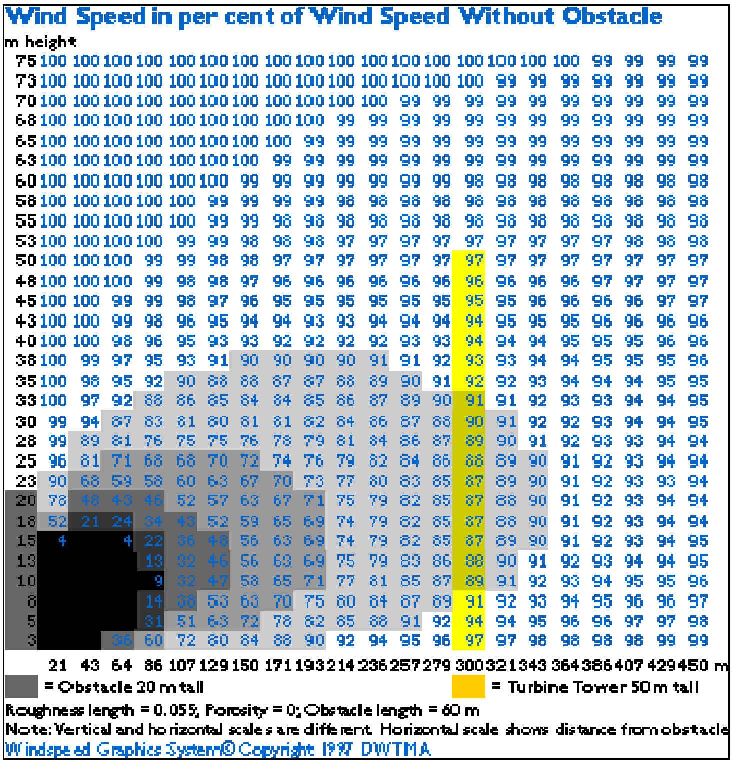
$z_0 = 0.1$

$z_{ref} = 20$ hence,

$v = 7.7 \ln(60/0.1) / \ln(20/0.1) = 9.2966$ m/s

The formula assumes so-called neutral atmospheric stability conditions, i.e. that the ground surface is neither heated nor cooled compared to the air temperature.

4.1.9 Wind Shade


Wind Speed in per cent of Wind Speed Without Obstacle

m height	21	43	64	86	107	129	150	171	193	214	236	257	279	300	321	343	364	386	407	429	450 m
75	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	99	99	99
73	100	100	100	100	100	100	100	100	100	100	100	100	100	100	99	99	99	99	99	99	99
70	100	100	100	100	100	100	100	100	100	100	100	99	99	99	99	99	99	99	99	99	99
68	100	100	100	100	100	100	100	100	100	99	99	99	99	99	99	99	99	99	99	99	99
65	100	100	100	100	100	100	100	100	99	99	99	99	99	99	99	99	99	99	99	99	99
63	100	100	100	100	100	100	100	99	99	99	99	99	99	99	99	99	99	99	99	99	99
60	100	100	100	100	100	100	99	99	99	99	99	99	99	98	98	98	98	98	98	98	98
58	100	100	100	100	100	99	99	99	99	98	98	98	98	98	98	98	98	98	98	98	98
55	100	100	100	100	100	99	99	98	98	98	98	98	98	98	98	98	98	98	98	98	98
53	100	100	100	100	99	99	98	98	98	97	97	97	97	97	97	97	97	97	98	98	98
50	100	100	100	99	99	98	98	97	97	97	97	97	97	97	97	97	97	97	97	97	97
48	100	100	100	99	98	98	97	96	96	96	96	96	96	96	96	96	96	97	97	97	97
45	100	100	99	99	98	97	96	95	95	95	95	95	95	95	95	96	96	96	96	97	97
43	100	100	99	98	96	95	94	94	93	93	94	94	94	94	95	95	95	96	96	96	96
40	100	100	98	96	95	93	93	92	92	92	92	93	93	94	94	94	95	95	95	96	96
38	100	99	97	95	93	91	90	90	90	90	91	91	92	93	93	94	94	95	95	95	96
35	100	98	95	92	90	88	88	87	87	88	89	90	91	92	92	93	94	94	94	95	95
33	100	97	92	88	86	85	84	84	85	86	87	89	90	91	91	92	93	93	94	94	95
30	99	94	87	83	81	80	81	81	82	84	86	87	88	90	91	92	92	93	94	94	95
28	99	89	81	76	75	75	76	78	79	81	84	86	87	89	90	91	92	93	93	94	94
25	96	81	71	68	68	70	72	74	76	79	82	84	86	88	89	90	91	92	93	94	94
23	90	68	59	58	60	63	67	70	73	77	80	83	85	87	89	90	91	92	93	93	94
20	78	48	43	46	52	57	63	67	71	75	79	82	85	87	88	90	91	92	93	94	94
18	52	21	24	34	43	52	59	65	69	74	79	82	85	87	88	90	91	92	93	94	94
15	4		4	22	36	48	56	63	69	74	79	82	85	87	89	90	91	92	93	94	95
13				13	32	46	56	63	69	75	79	83	86	88	90	91	92	93	94	94	95
10				9	32	47	58	65	71	77	81	85	87	89	91	92	93	94	95	95	96
8				14	38	53	63	70	75	80	84	87	89	91	92	93	94	95	96	96	97
5				31	51	63	72	78	82	85	88	91	92	94	94	95	96	96	97	97	98
3			36	60	72	80	84	88	90	92	94	95	96	97	97	98	98	98	98	99	99

▨ = Obstacle 20 m tall
🟨 = Turbine Tower 50 m tall

Roughness length = 0.055; Porosity = 0; Obstacle length = 60 m
Note: Vertical and horizontal scales are different. Horizontal scale shows distance from obstacle
Windspeed Graphics System© Copyright 1997 DWTMA

Figure 4.3: Example of Wind Shade [13].

This above figure provides an estimate of how wind speeds decrease behind a blunt obstacle, i.e. an obstacle which is not nicely streamlined. In this case we use a seven story office building, 20 metres tall and 60 metres wide placed at a distance of 300 m from a wind turbine with a 50 m hub height. You can quite literally see the wind shade as different shades of grey. The blue numbers indicate the wind speed in per cent of the wind speed without the obstacle. At the top of the yellow wind turbine tower the wind speed has decreased by some 3 per cent to 97 per cent of the speed without the obstacle. Noted that this means a loss of wind energy of some 10 per cent.

4.1.10 Wake Effect

Since a wind turbine generates electricity from the energy in the wind, the wind leaving the turbine must have a lower energy content than the wind arriving in front of the turbine.

Figure 4.4 : The Wake effect [14].

This follows directly from the fact that energy can neither be created nor consumed. A wind turbine will always cast a wind shade in the downwind direction. In fact, there will be a wake behind the turbine, i.e. a long trail of wind which is quite turbulent and slowed down, when compared to the wind arriving in front of the turbine. (The expression wake is obviously derived from the wake behind a ship). Wind turbines in parks are usually spaced at least three rotor diameters from one another in order to avoid too much turbulence around the turbines downstream. In the prevailing wind direction turbines are usually spaced even farther apart.

4.1.11 Wind Turbine Towers

The tower of the wind turbine carries the nacelle and the rotor. Towers for large wind turbines may be either tubular steel towers, lattice towers, or concrete towers. Guyed tubular towers are only used for small wind turbines (battery chargers etc.)

Most large wind turbines are delivered with tubular steel towers, which are manufactured in sections of 20-30 metres with flanges at either end, and bolted together on the site. The towers are conical (i.e. with their diameter increasing towards the base) in order to increase their strength and to save materials at the same time.

Lattice towers are manufactured using welded steel profiles. The basic advantage of lattice towers is cost, since a lattice tower requires only half as much material as a freely standing tubular tower with a similar stiffness. The basic disadvantage of lattice towers is their visual appearance, (although that issue is clearly debatable). For aesthetic reasons, lattice towers have almost disappeared from use for large, modern wind turbines.

Many small wind turbines are built with narrow pole towers supported by guy wires. The advantage is weight savings, and thus cost. The disadvantages are difficult access around the towers which make them less suitable in farm areas. Finally, this type of tower is more prone to vandalism, thus compromising overall safety.

Some towers are made in different combinations of the techniques mentioned above. Such a hybrid design is a corss bread between a lattice tower and a guyed tower.

The price of a tower for a wind turbine is generally around 20 per cent of the total price of the turbine. For a tower around 50 metres' height, the additional cost of another 10 metres of tower is about 15,000 USD. It is therefore quite important for the final cost of energy to build towers as optimally as possible. Lattice towers are the cheapest to manufacture, since they typically require about half the amount of steel used for a tubular steel tower.

Generally, it is an advantage to have a tall tower in areas with high terrain roughness, since the wind speeds increases farther away from the ground, as we learned on the page about wind shear. Lattice towers and guyed pole towers have the advantage of giving less wind shade than a massive tower.

The rotor blades on turbines with relatively short towers will be subject to very different wind speeds (and thus different bending) when a rotor blade is in its top and in its bottom position, which will increase the fatigue loads on the turbine.

Each metre of tower height costs money, of course, so the optimum height of the tower is a function of

1. tower costs per metre (10 metre extra tower will presently cost you about 15,000 USD)
2. how much the wind locally varies with the height above ground level, i.e. the average local terrain roughness (large roughness makes it more useful with a taller tower),
3. the price the turbine owner gets for an additional kilowatt hour of electricity.

Manufacturers often deliver machines where the tower height is equal to the rotor diameter. aesthetically, many people find that turbines are more pleasant to look at, if the tower height is roughly equal to the rotor diameter.

4.1.12 Weibull Distribution

It is very important that the wind industry has the prior knowledge of the variation of wind speeds. A turbine designer needs this kind of information to optimise the design of his/her turbines, so as to minimise generating costs. Turbine investors need the information to estimate their return of investment from electricity generation. If measurement of wind speeds are made throughout the year, the chances are that in most areas, strong gale force winds are quite rare, while moderate and fresh winds are quite common.

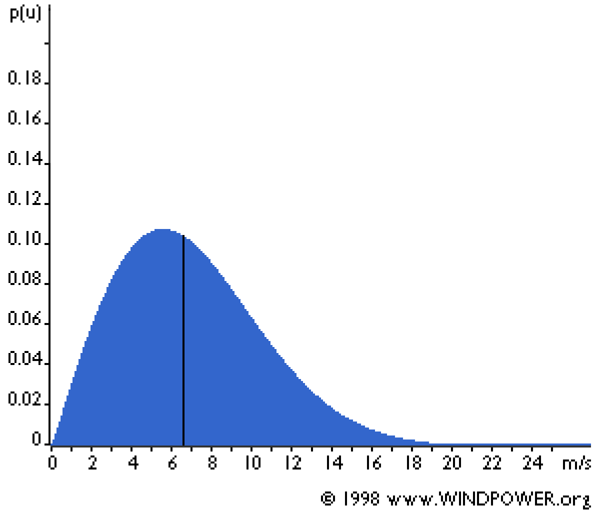


Figure 4.5: Weibull Pattern [15].

The wind variation for a typical site is usually described using the so-called Weibull distribution, as shown in Figure 4.5. This particular site has a mean wind speed of 7 metres per second, and the shape of the curve is determined by a so called shape parameter of 2.

Figure 5.1 is actually a graph that shows a probability density distribution. The area under the curve is always exactly 1, since the probability that the wind will be blowing at some wind speed including zero must be 100 per cent.

Half of the grey area is to the left of the vertical black line at 6.6 metres per second. The 6.6 m/s is called the median of the distribution. This means that half the time it will be blowing less than 6.6 metres per second, the other half it will be blowing faster than 6.6 metres per second.

As can be ssen, the distribution is not symmetrical. Sometimes very high wind speeds will occur, but they are rare. Wind speeds of 5.5 metres per second, on the other hand, are the most common ones. 5.5 metres is called the modal value of the distribution. If we multiply each tiny wind speed interval by the probability of getting that particular wind speed, and add it all up, the mean wind speed will be obtained.

The statistical distribution of wind speeds varies from place to place around the globe, depending upon local climate conditions, the landscape, and its surface. The Weibull distribution may thus vary, both in its shape, and in its mean value.

4.1.13 Wind Average Power of the Wind

The reason why wind speeds is important is due to their energy content. Taking the Weibull distribution of wind speeds, and for each speed if a bottle is place on a shelf each time we have a 1 per cent probability of getting that wind speed. The size of each bottle corresponds to the wind speed, so the weight of each bottle corresponds to the amount of energy in the wind.

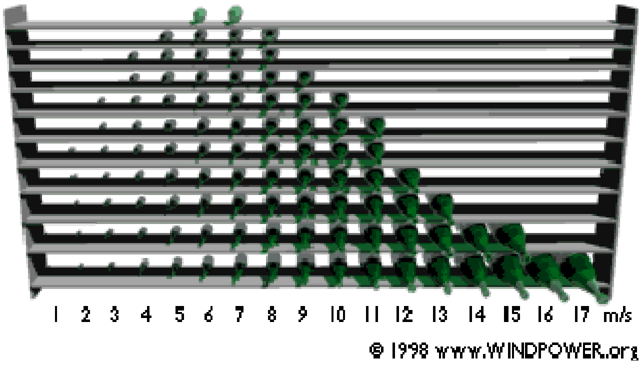


Figure 4.6: Bottle on rack analogy [16].

With reference to Figure 4.6, looking to the right, at 17 m/s some very heavy bottles, which weigh almost 5000 times as much as the bottles at 1 m/s. (At 1 m/s the wind has a power of 0.61 W/m ^{2}. At 17 m/s its power is 3009 W/m ^{2}).

Finding the wind speed at which the mean of the power distribution can be obtained, is equivalent to balancing the bookshelves. So, in this case with an average wind speed of 7 m/s, the power weighted average of wind speeds is 8.7 m/s. At that wind speed the power of the wind is 402 W/m ^{2}.

4.1.14 Betz' Law

The more kinetic energy a wind turbine pulls out of the wind, the more the wind will be slowed down as it leaves the left side of the turbine. If an effort is made to extract all the energy from the wind, the air would move away with the speed zero, i.e. the air could not leave the turbine. In such a case, the extraction of energy is not possible as all of the air would obviously also be prevented from entering the rotor of the turbine.

In another extreme case, the wind could pass though the wind turbine without being hindered at all. In this case the extraction of energy from the wind does not happen. It is therefore assume that there must be some way of braking the wind which is in between these two extremes, and is more efficient in converting the energy in the wind to useful mechanical energy. An ideal wind turbine will slow down the wind by 2/3 of its original speed. Betz' law says that you can only convert less than 16/27 (or 59%) of the kinetic energy in the wind to mechanical energy using a wind turbine.

4.1.15 Power Density

It is well understood that the energy potential per second varies in proportion to the cube (the third power) of the wind speed, and in proportion to the density of the air. (Its weight per unit of volume).

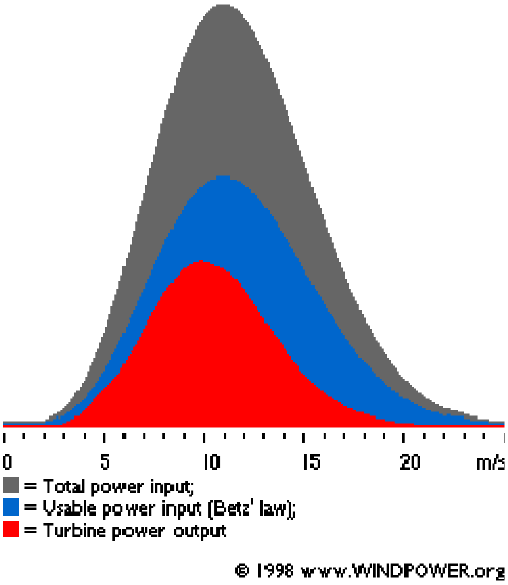


Figure 4.7: Graph of power generation [16]

If the power of each wind speed is multiplied with the probability of each wind speed from the Weibull graph, the power density will be obtained.

The area under the grey curve (all the way to the axis at the bottom) provide the information on the amount of wind power per square metre wind flow we may expect at this particular site. For example if a mean wind speed of 7 m/s is obtained and a Weibull k=2, the power density will be obtained 402 W/m ^{2}. It is important to note that this is almost twice as much power as the wind has when it is blowing constantly at the average wind speed.

The most important thing to take not is that the bulk of wind energy is found at wind speeds above the mean (average) wind speed at the site. This come as no surprise because it is a known fact that high wind speeds have much higher energy content than low wind speeds.

While still referring to the above Figure it is important to mention that wind turbines are designed to start running at speeds of between 3 to 5 metres per second. This is called the *cut in wind speed*. The blue area to the left shows the small amount of power we lose due to the fact the turbine only cuts in after, say 5 m/s. The wind turbine will be programmed to stop at high wind speeds above, say 25 metres per second, in order to avoid damaging the turbine or its surroundings. The stop wind speed is called the *cut out wind speed*. The tiny blue area to the right represents that loss of power.

4.1.16 Wind Turbine Power Curve

The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds.

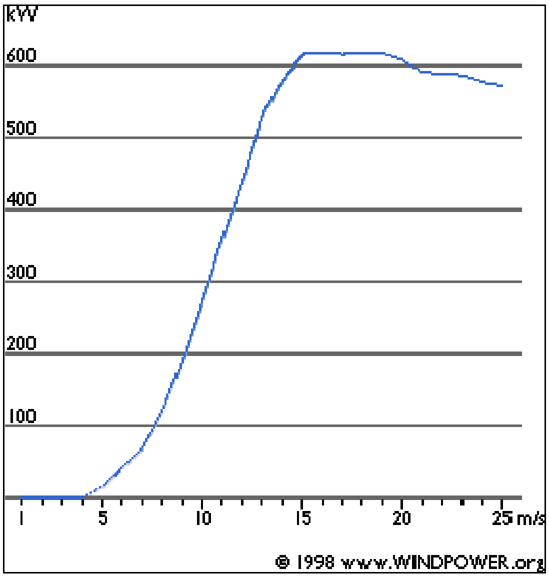


Figure 4.8: Example of a power curve [17].

Figure 4.8 shows a power curve for a typical Danish 600 kW wind turbine. Power curves are found by field measurements, where an anemometer is placed on a mast reasonably close to the wind turbine (not on the turbine itself or too close to it, since the turbine rotor may create turbulence, and make wind speed measurement unreliable).

If the wind speed is not fluctuating too rapidly during the field trial, it is recommended that the wind speed measurements from the anemometer and read the electrical power output from the wind turbine and plot the two values together in a graph like the one to the left.

4.1.17 Power Coefficient

The power coefficient provides information as to how efficiently a turbine is able to convert the energy in the wind to electricity.

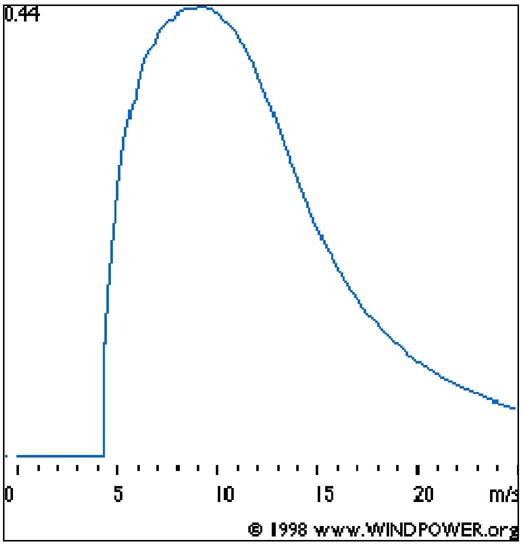


Figure 4.9: Example of a Danish wind turbine power coefficient. [18].

If the electrical power output is divided by the wind energy input, it will enable an operator to measure how technically efficient a wind turbine is. In other words, by taking the power curve and divide it by the area of the rotor, the power output per square metre of rotor area will be obtained. For each wind speed, the result will be divided by the amount of power in the wind, per square metre.

Figure 4.9 shows a power coefficient curve for a typical Danish wind turbine. Although the average efficiency for these turbines is somewhat above 20 per cent, the efficiency varies very much with the wind speed. (If there are small kinks in the curve, they are usually due to measurement errors).

As can be seen, the mechanical efficiency of the turbine is largest (in this case 44 per cent) at a wind speed around some 9 m/s. This is a deliberate choice by the engineers who designed the turbine. At low wind speeds efficiency is not so important, because there is not much energy to harvest. At high wind speeds the turbine must waste any excess energy above what the generator was designed for. Efficiency therefore matters most in the region of wind speeds where most of the energy is to be found.

4.1.18 Calculation Of Wind Power

There are many complicated calculations and equations involved in understanding and constructing wind turbine generators. however the layman need not worry about most of these and should instead ensure they remember the following vital information:

i) The power output of a wind generator is proportional to the area swept by the rotor - i.e. double the *swept area* and the power output will also double.

ii) The power output of a wind generator is proportional to the cube of the wind speed - i.e. double the *wind speed* and the power output will increase by a factor of eight (2 x 2 x 2).

Wind is made up of moving air molecules which have a certain quantity of mass. Any moving object with mass carries kinetic energy in an amount is given by the following equation:

$$\text{Kinetic Energy} = 0.5 \times \text{Mass} \times \text{Velocity}^2$$

where the mass is measured in kg, the velocity in m/s, and the energy is given in joules.

Air has a known density (around 1.23 kg/m^3 at sea level), so the mass of air hitting our wind turbine (which sweeps a known area) each second is given by the following equation:

$$\text{Mass/sec (kg/s)} = \text{Velocity (m/s)} \times \text{Area } (m^2) \times \text{Density } (kg/m^3)$$

And therefore, the power (i.e. energy per second) in the wind hitting a wind turbine with a certain swept area is given by simply inserting the *mass per second* calculation into the standard kinetic energy equation given above resulting in the following vital equation:

$$\text{Power} = 0.5 \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3$$

where Power is given in Watts (i.e. joules/second), the Swept area in square metres, the Air density in kilograms per cubic metre, and the Velocity in metres per second.

The world's largest wind turbine generator has a rotor blade diameter of 126 metres and so the rotors sweep an area of PI x $(\text{diameter}/2)^2$ = 12470 m^2 As this is an offshore wind turbine, which it is situated at sea-level and so the air density can be taken as 1.23 kg/m^3. The turbine is rated at 5MW in 30mph (14m/s) winds, and so putting in the known values the following information is obtained:

$$\text{Wind Power} = 0.5 \times 12{,}470 \times 1.23 \times (14 \times 14 \times 14)$$

which gives the magnitude for the wind power of around 21,000,000 Watts. Why is the power of the wind (21MW) so much larger than the rated power of the turbine generator (5MW)? This is because of the Betz Limit, and inefficiencies in the system.

4.1.19 Wind Turbine Generators

The wind turbine generator converts mechanical energy to electrical energy. Wind turbine generators are a bit unusual, compared to other generating units you ordinarily find attached to the electrical grid. One reason is that the generator has to work with a power source (the wind turbine rotor) which supplies very fluctuating mechanical power (torque).

On large wind turbines (above 100-150 kW) the voltage (tension) generated by the turbine is usually 690 V three-phase alternating current (AC). The current is subsequently sent through a transformer next to the wind turbine (or inside the tower) to raise the voltage to somewhere between 10,000 and 30,000 volts, depending on the standard in the local electrical grid.

Generators need cooling while they work. On most turbines this is accomplished by encapsulating the generator in a duct, using a large fan for air cooling, but a few manufacturers use water cooled generators. Water cooled generators may be built more compactly, which also gives some electrical efficiency advantages, but they require a radiator in the nacelle to get rid of the heat from the liquid cooling system. If a large wind turbine generator is connected to the grid by flicking an ordinary switch, this will be quite likely to damage both the generator, the gearbox and the current in the grid in the neighbourhood.

Wind turbines are to be designed with either synchronous or asynchronous generators, and with various forms of direct or indirect grid connection of the generator. Direct grid connection mean that the generator is connected directly to the (usually 3-phase) alternating current grid. Indirect grid connection means that the current from the turbine passes through a series of electric devices which adjust the current to match that of the grid. With an asynchronous generator this occurs automatically.

The power from the rotation of the wind turbine rotor is transferred to the generator through the power train, which is through the main shaft, the gearbox and the high speed shaft. If an ordinary generator is used, directly connected to a 50 Hz AC (alternating current) three phase grid with two, four, or six poles, an extremely high speed turbine will be produced which is between 1000 and 3000 rpm. And if the turbine has a 43 metre rotor diameter, that would imply a tip speed of the rotor of far more than twice the speed of sound, which impractical and dangerous. Another possibility is to build a slow-moving AC generator with many poles. But if it is to be connected to the grid directly, the system will end up with a 200 pole generator (i.e. 300 magnets) to arrive at a reasonable rotational speed of 30 rpm. Another problem is, that the mass of the rotor of the generator has to be roughly proportional to the amount of torque (moment, or turning force) it has to handle. So a directly driven generator will be very heavy (and expensive) in any case.

The practical solution, which is used in the opposite direction in lots of industrial machinery, and in connection with car engines is to use a gearbox. With a gearbox you convert between slowly rotating, high torque power which you get from the wind turbine rotor - and high speed, low torque power, which you use for the generator.

The gearbox in a wind turbine does not "change gears". It normally has a single gear ratio between the rotation of the rotor and the generator. For a 600 or 750 kW machine, the gear ratio is typically approximately 1 to 50.

4.1.20 Wind Turbine Controller

The wind turbine controller consists of a data acquisition and controlling system which continuously monitor the condition of the wind turbine and collect statistics on its operation. As the name implies, the controller also controls a large number of switches, hydraulic pumps, valves, and motors within the wind turbine. As wind turbine sizes increase to megawatt machines, it becomes even more important that they have a high availability rate, i.e. that they function reliably all the time.

The controller communicates with the owner or operator of the wind turbine via a communications link, e.g. sending alarms or requests for service over the telephone or a radio link. It is also possible to call the wind turbine to collect statistics, and check its present status. In wind parks one of the turbines will usually be equipped with a PC from which it is possible to control and collect data from the rest of the wind turbines in the park. This PC can be called over a telephone line or a radio link.

There is usually a controller both at the bottom of the tower and in the nacelle. On recent wind turbine models, the communication between the controllers is usually done using fibre optics. The image to the right shows a fibre optics communications unit. On some recent models, there is a third controller placed in the hub of the rotor. That unit usually communicates with the nacelle unit using serial communications through a cable connected with slip rings and brushes on the main shaft.

Computers and sensors are usually duplicated (redundant) in all safety or operation sensitive areas of newer, large machines. The controller continuously compares the readings from measurements throughout the wind turbine to ensure that both the sensors and the computers themselves are OK. The picture at the top of the page shows the controller of a megawatt machine, and has two central computers.

The controller main role check the rotational speed of the rotor, the generator, its voltage and current. In addition, lightning strikes and their charge may be registered. Furthermore measurements may be made of of outside air temperature, temperature in the electronic cabinets, oil temperature in the gearbox, the temperature of the generator windings, the temperature in the gearbox bearings, hydraulic pressure, the pitch angle of each rotor blade (for pitch controlled or active stall controlled machines), the yaw angle (by counting the number of teeth on yaw wheel), the number of power cable twists, wind direction, wind speed from the anemometer, the size and frequency of vibrations in the nacelle and the rotor blades, the thickness of the brake linings, whether the tower door is open or closed (alarm system).

Many of the business secrets of the wind turbine manufacturers are to be found in the way the controller interacts with the wind turbine components. Improved control strategies are responsible for an important part of the increase in wind turbine productivity in recent years. An interesting strategy pursued by some manufacturers is to adapt the operational strategy to the local wind climate. In this way it may e.g. be possible to minimise uneconomic tear and wear on the machine during (rare) periods of rough weather.

4.1.21 Power Quality Controller

Controller is assumed as the unit which runs the wind turbine, e.g. yaws it against the wind, monitor the safety systems are in order, and starts the turbine. The controller does indeed do all these things, but it also looks after the power quality of the current generated by the wind turbine.

Voltage and current are typically measured 128 times per alternating current cycle, (i.e. 50 x 128 times per second or 60 x 128 times per second, depending on the electrical grid frequency). On this basis, a so called DSP processor calculates the stability of the grid frequency and the active and reactive power of the turbine. (The reactive power component is basically a question of whether the voltage and the current are in phase or not).

In order to ensure the proper power quality, the controller may switch on or switch off a large number of electrical capacitors which adjust the reactive power, (i.e. the phase angle between the voltage and the current). As you can see in the image to the left, the switchable capacitor bank is quite a large control unit in itself in a megawatt sized machine.

4.1.22 Basic Load Design Considerations

Strength, dynamic behaviour and fatigue properties of the materials associated with the wind turbine will have to be taken into consideration before the complete system is designed and construct.

Turbines with many blades or very wide blades, i.e. turbines with a very solid rotor, however, will be subject to very large forces, when the wind blows at a hurricane speed. (Remember, that the energy content of the wind varies with the third power (the cube) of the wind speed).

Wind turbine manufacturers have to certify that their turbines when built are able to withstand extreme winds which occur, say, during 10 minutes once every 50 years. To limit the influence of the extreme winds turbine manufacturers therefore prefer to build turbines with a few, long, narrow blades.

In order to make up for the narrowness of the blades facing the wind, turbine manufacturers prefer to let the turbine rotate relatively quickly. Wind turbines are subject to fluctuating winds , and hence fluctuating forces. This is particularly the case if they are located in a very turbulent wind climate.

Components which are subject to repeated bending, such as rotor blades, may eventually develop cracks which ultimately may make the component break. A historical example is the huge German Growian machine (100 m rotor diameter) which had to be taken out of service after less than three weeks of operation. Metal fatigue is a well known problem in many industries. Metal is therefore generally not favoured as a material for rotor blades.

When designing a wind turbine it is required to calculate in advance how the different components will vibrate, both individually, and jointly. It is also important to calculate the forces involved in each bending or stretching of a component. This is the subject of structural dynamics, where physicists have developed mathematical computer models that analyse the behaviour of an entire wind turbine. These models are used by wind turbine manufacturers to design their machines safely.

A 50 metre tall wind turbine tower will have a tendency to swing back and forth, say, every three seconds. The frequency with which the tower oscillates back and forth is also known as the eigenfrequency of the tower. The eigenfrequency depends on both the height of the tower, the thickness of its walls, the type of steel, and the weight of the nacelle and rotor. Now, each time a rotor blade passes the wind shade of the tower, the rotor will push slightly less against the tower. If the rotor turns with a rotational speed such that a rotor blade passes the tower each time the tower is in one of its extreme positions, then the rotor blade may either dampen or amplify (reinforce) the oscillations of the tower. The rotor blades themselves are also flexible, and may have a tendency to vibrate, say, once per second. As you can see, it is very important to know the eigenfreqencies of each component in order to design a safe turbine that does not oscillate out of control.

4.1.23: The Choice of Horizontal and Vertical Axis

The most favourable choice of a wind turbine world wide is the horizontal axis type. The reason is simple: All grid-connected commercial wind turbines today are built with a propeller-type rotor on a horizontal axis (i.e. a horizontal main shaft). The purpose of the rotor, of course, is to convert the linear motion of the wind into rotational energy that can be used to drive a generator. The same basic principle is used in a modern water turbine, where the flow of water is parallel to the rotational axis of the turbine blades.

The only vertical axis turbine which has ever been manufactured commercially is the Darrieus machine, named after the French engineer Georges Darrieus who patented the design in 1931. The Darrieus machine is characterised by its C-shaped rotor blades which make it look a bit like an eggbeater. It is normally built with two or three blades. The basic theoretical advantages of a vertical axis machine are:

1) You may place the generator, gearbox etc. on the ground, and you may not need a tower for the machine.
2) You do not need a yaw mechanism to turn the rotor against the wind.

The basic disadvantages are:

1) Wind speeds are very low close to ground level, the wind speeds will be very low on the lower part of the rotor.
2) The overall efficiency of the vertical axis machines is not impressive.
3) The machine is not self-starting (e.g. a Darrieus machine needs a assistance to rotate).
4) The machine may need wires to hold it up, but the wires are impractical in heavily farmed areas.
5) Replacing the main bearing for the rotor necessitates removing the rotor on both a horizontal and a vertical axis machine.

4.1.24 The Choice of Upwind or Downwind Machines

Upwind machines have the rotor facing the wind. The basic advantage of upwind designs is to avoid the wind shade behind the tower. The vast majority of wind turbines worldwide enherit this type of design design. On the other hand, there is also some wind shade in front of the tower, i.e. the wind starts bending away from the tower before it reaches the tower itself, even if the tower is round and smooth.

Therefore, each time the rotor passes the tower, the power from the wind turbine drops slightly. The basic drawback of upwind designs is that the rotor needs to be made rather inflexible, and placed at some distance from the tower (as some manufacturers have found out to their cost). In addition an upwind machine needs a yaw mechanism to keep the rotor facing the wind.

Downwind machines have the rotor placed on the lee side of the tower. They have the theoretical advantage that they may be built without a yaw mechanism, if the rotor and nacelle have a suitable design that makes the nacelle follow the wind passively. For large wind turbines, it provide the advantage since there is no need for cables to lead the current away from the generator.

A more important advantage is that the rotor may be made more flexible. This is an advantage both in regard to weight, and the structural dynamics of the machine, i.e. the blades will bend at high wind speeds, thus taking part of the load off the tower. The basic advantage of the downwind machine is thus, that it may be built somewhat lighter than an upwind machine. The basic drawback is the fluctuation in the wind power due to the rotor passing through the wind shade of the tower. This may give more fatigue loads on the turbine than with an upwind design.

4.1.25 The Choice of Number of Blades

Modern wind turbine engineers will avoid building large machines with an even number of rotor blades. The most important reason is the stability of the turbine. A rotor with an odd number of rotor blades (and at least three blades) can be considered to be similar to a disc when calculating the dynamic properties of the machine. A rotor with an even number of blades will give stability problems for a machine with a stiff structure. The reason is that at the very moment when the uppermost blade bends backwards, because it gets the maximum power from the wind, the lowermost blade passes into the wind shade in front of the tower.

Most modern wind turbines are three-bladed designs with the rotor position maintained upwind (on the windy side of the tower) using electrical motors in their yaw mechanism. This design is called the ‘classical Danish concept’ , and tends to be a standard against which other concepts are evaluated. The vast majority of the turbines sold in world markets have this design. Another characteristic is the use of an asynchronous generator.

Two-bladed wind turbine designs have the advantage of saving the cost of one rotor blade and its weight, of course. However, they tend to have difficulty in penetrating the market, partly because they require higher rotational speed to yield the same energy output. This is a disadvantage both in regard to noise and visual intrusion. Lately, several traditional manufacturers of two-bladed machines have switched to three-bladed designs.

Two-bladed require a more complex design with a hinged (teetering hub) rotor, i.e. the rotor has to be able to tilt in order to avoid too heavy shocks to the turbine when a rotor blades passes the tower. The rotor is therefore fitted onto a shaft which is perpendicular to the main shaft, and which rotates along with the main shaft. This arrangement may require additional shock absorbers to prevent the rotor blade from hitting the tower.

4.1.26 Optimizing the Performance of the Wind Turbine

The water pumping windmills to the left look very different from modern, large wind turbines. But they are quite sensibly designed for the purpose they serve: The very solid rotor with many blades means that they will be running even at very low wind speeds, and thus pumping a fair amount of water all year round.

Clearly, they will be very inefficient at high wind speeds, and they will have to shut themselves down, and yaw out of the wind in order to avoid damage to the turbine, due to the very solid rotor. But that does not really matter: We do not want them to empty the wells and flood the water tank during a gale. The ideal wind turbine design is not dictated by technology alone, but by a combination of technology and economics: Wind turbine manufacturers wish to optimise their machines, so that they deliver electricity at the lowest possible cost per kilowatt hour (kWh) of energy.

But manufacturers are not very concerned about how efficiently they use the wind resource: The fuel is free, after all. It is not necessarily a good idea to maximise annual energy production, if that means that one has to build a very expensive wind turbine. In the next sections we shall look at some of the choices manufacturers have to make.

A small generator, (i.e. a generator with low rated power output in kW) requires less force to turn than a large one. If you fit a large wind turbine rotor with a small generator it will be producing electricity during many hours of the year, but it will capture only a small part of the energy content of the wind at high wind speeds. A large generator, on the other hand, will be very efficient at high wind speeds, but unable to turn at low wind speeds.

Clearly, manufacturers will look at the distribution of wind speeds and the energy content of the wind at different wind speeds to determine the ideal combination of the size of the rotor and the size of the generator at different wind turbine sites. Fitting a wind turbine with two (or more) generators can sometimes be an advantage, but whether it really pays to do it depends on the electricity price.

4.1.27 Mechanical Noise Reduction

Sound emissions from wind turbines comes from two different sources: Mechanical noise, and aerodynamic noise . Mechanical noise, i.e. metal components moving or rubbing against each other may originate in the gearbox, in the drive train, and in the generator of a wind turbine. Machines from the early 1980s or before do emit some mechanical noise, which may be heard in the immediate surroundings of the turbine, in the worst cases even up to a distance of 200 m.

A survey on research and development priorities of Danish wind turbine manufacturers conducted in 1995, however, showed that no manufacturer considered mechanical noise as a problem any longer, and therefore no further research in the area was considered necessary. The reason was, that within three years noise emissions had dropped to half their previous level due to better engineering practices.

Gearboxes for wind turbines are no longer standard industrial gearboxes, but they have been adapted specifically for quiet operation of wind turbines. The solution this is to ensure that the steel wheels of the gearbox have a semi-soft, flexible core, but a hard surface to ensure strength and long time wear. This can be is done by heating the gear wheels after their teeth have been ground, and then let them cool off slowly while they are packed in a special high carbon-content powder. The carbon will then migrate into the surface of the metal. This ensures a high carbon content and high durability in the surface of the metal, while the steel alloy in the interior remains softer and more flexible.

Resonance generated by different components is a typical program with an integrated mechaincal system which is not fully secured. An important consideration, which enters into the turbine design process today, is the fact that the rotor blades may act as membranes that may retransmit noise vibrations from the nacelle and tower.

Turbine manufacturers nowadays make computer models of their machines before building them, to ensure that the vibrations of different components do not interact to amplify noise. When one examine at the chassis frame of a wind turbine nacelle on the market today, there will be some odd holes which were drilled into the chassis frame for no apparent reason. These holes were precisely made to ensure that the frame will not vibrate in step with the other components in the turbine.

Sound insulation plays a minor role in most wind modern turbines on the market today, although it can be useful to minimise some medium- and high-frequency noise. In general, however, it seems to be more efficient to attack noise problems at the source, in the structure of the machine itself.

4.1.28 Aerodynamic Noise Reduction

When the wind hits different objects at a certain speed, it will start to make a sound. If it hits the leaves of trees and bushes, or a water surface it will create a random mixture of high frequencies, which is often called white noise. The wind may also set surfaces in vibration, as sometimes happens with parts of a building, a car or even an (engineless) glider aeroplane. These surfaces in turn emit their own sound. If the wind hits a sharp edge, it may produce a pure tone, as with some musical wind instruments.

Rotor blades make a slight swishing sound which will be heard close to a wind turbine, at relatively low wind speeds. Rotor blades must brake the wind to transfer energy to the rotor. In the process they cause some emission of white noise. If the surfaces of the rotor blades are very smooth, the surfaces will emit a minor part of the noise. Most of the noise will originate from the trailing (back) edge of the blades. Careful design of trailing edges and very careful handling of rotor blades while they are mounted, have become routine practice in the industry. Other things being equal, sound pressure will increase with the fifth power of the speed of the blade relative to the surrounding air. It is thus natural that modern wind turbines with large rotor diameters have very low rotational speed.

Since the tip of the blade moves substantially faster than the root of the blade, great care must be taken about the design of the rotor tip. If one look closely at different rotor blades he/she will discover subtle changes in their geometry over time, as more and more research in the area is being done. The research is also done for performance reasons, since most of the torque (rotational moment) of the rotor comes from the outer part of the blades. In addition, the airflows around the tip of rotor blades is extremely complex, compared to the airflow over the rest of the rotor blade.

4.1.29 Cost

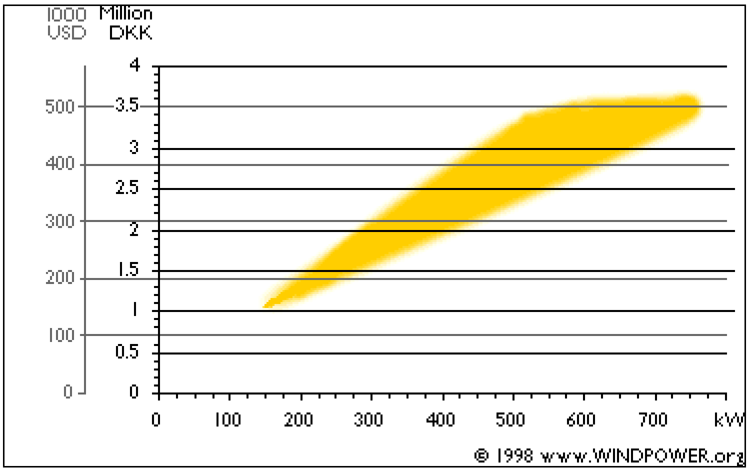


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Figure 4.10: Capacity versus cost for wind turbine [19].

The graph above gives an impression of the price range of modern, Danish grid connected wind turbines as of February 1998. At today's price the cost factor could have gone up by a factor of 1.5 to 2.0. As shown in Figure 4.10 the prices vary for each generator size. The reasons are e.g. different tower heights, and different rotor diameters. One extra metre of tower will cost you roughly 1 500 USD. A special low wind machine with a relatively large rotor diameter will be more expensive than a high wind machine with a small rotor diameter.

Moving from a 150 kW machine to a 600 kW machine, prices will roughly triple, rather than quadruple. The reason is, that there are economies of scale up to a certain point, e.g. the amount of manpower involved in building a 150 kW machine is not very different from what is required to build a 600 kW machine. E.g. the safety features, and the amount of electronics required to run a small or a large machine is roughly the same. There may also be (some) economies of scale in operating wind parks rater than individual turbines, although such economies tend to be rather limited.

Even if prices are very similar in the range from 600 to 750 kW, you would not necessarily want to pick a machine with as large a generator as possible. A machine with a large 750 kW generator (and a relatively small rotor diameter) may generate less electricity than, say a 600 kW machine, if it is located in a low wind area. The working horse today is typically a 1000 kilowatt machine with a tower height of some 60 to 80 metres and a rotor diameter of around 54 metres. The average price for large, modern wind farms is around 1 000 USD per kilowatt electrical power installed.

4.1.30 Operation and Maintenance Costs

Modern wind turbines are designed to work for some 120 000 hours of operation throughout their design lifetime of 20 years. That is far more than an automobile engine which will generally last for some 4 000 to 6 000 hours.

Experience shows that maintenance cost are generally very low while the turbines are brand new, but they increase somewhat as the turbine ages. Studies done on the 5000 Danish wind turbines installed in Denmark since 1975 show that newer generations of turbines have relatively lower repair and maintenance costs that the older generations. (The studies compare turbines which are the same age, but which belong to different generations).

Older Danish wind turbines (25-150 kW) have annual maintenance costs with an average of around 3 per cent of the original turbine investment. Newer turbines are on average substantially larger, which would tend to lower maintenance costs per kW installed power (you do not need to service a large, modern machine more often than a small one). For newer machines the estimates range around 1.5 to 2 per cent per year of the original turbine investment.

Most of maintenance cost is a fixed amount per year for the regular service of the turbines, but some people prefer to use a fixed amount per kWh of output in their calculations, usually around 0.01 USD/kWh. The reasoning behind this method is that tear and wear on the turbine generally increases with increasing production.

Other than the economies of scale which vary with the size of the turbine, mentioned above, there may be economies of scale in the operation of wind parks rather than individual turbines. These economies are related to the semi-annual maintenance visits, surveillance and administration, etc.

Some wind turbine components are more subject to tear and wear than others. This is particularly true for rotor blades and gearboxes. Wind turbine owners who see that their turbine is close the end of their technical design lifetime may find it advantageous to increase the lifetime of the turbine by doing a major overhaul of the turbine, e.g. by replacing the rotor blades. The price of a new set of rotor blades, a gearbox, or a generator is usually in the order of magnitude of 15-20 per cent of the price of the turbine.

The components of Danish wind turbines are designed to last 20 years. It would, of course, be possible to design certain components to last much longer, but it would really be a waste, if other major components were to fail earlier. The 20 year design lifetime is a useful economic compromise which is used to guide engineers who develop components for the turbines. Their calculations have to prove that their components have a very small probability of failure before 20 years have elapsed.

The actual lifetime of a wind turbine depends both on the quality of the turbine and the local climatic conditions, e.g. the amount of turbulence at the site, as explained in the page on turbine design and fatigue loads. Offshore turbines may e.g. last longer, due to low turbulence at sea. This may in turn lower costs, as shown in the graph on the page on the Economics of Offshore Wind Turbines.

4.1.31 Income

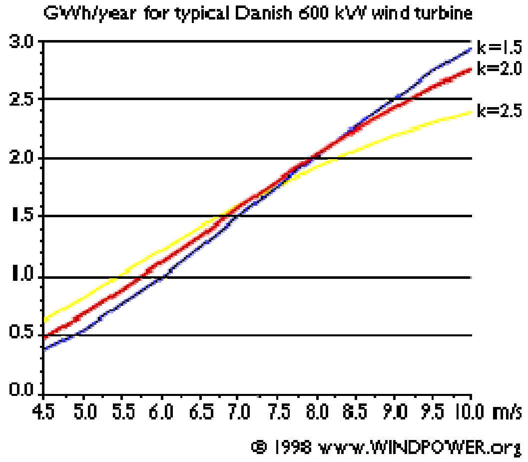


Figure 4.11: Income versus wind speed [20].

Figure 4.11 shows how annual energy production in million kilowatt hours varies with the windiness of the site. With a mean wind speed of, say 6.75 metres per second at hub height you get about 1.5 million kilowatt hours of energy per year. Annual energy output varies roughly with the cube of the wind speed at turbine hub height. Just how sensitive energy production is to wind speed varies with the probability distribution for the wind, as explained in the page on the Weibull distribution. In this graph we have three examples with different k-values (shape factors). The red curve is referred as an example.

The figures for annual energy output assume that wind turbines are operational and ready to run all the time. In practice, however, wind turbines need servicing and inspection once every six months to ensure that they remain safe. In addition, component failures and accidents (such as lightning strikes) may disable wind turbines. Very extensive statistics show that the best turbine manufacturers consistently achieve availability factors above 98 per cent, i.e. the machines are ready to run more than 98 per cent of the time. Total energy output is generally affected less than 2 per cent, since wind turbines are never serviced during high winds. Such a high degree of reliability is remarkable, compared to other types of machinery, including other electricity generating technologies. The availability factor is therefore usually ignored when doing economic calculations, since other uncertainties (e.g. wind variability) are far larger.

4.2 Wind Energy for Sabah

Wind turbines convert the kinetic energy of wind into electricity. Wind turbines are typically constructed at least 30m above ground, where air moves faster and with less turbulence. A single wind turbine can have a peak capacity of up to several MW, but several turbines are typically grouped together in utility-scale wind farms to make power plants with a capacity in the tens to hundreds of MW. Wind energy consumes no fuel, produces no emissions, and the energy required for manufacturing is usually recouped within a few months. Some environmentalists have raised concerns about danger to birds and bats, especially during key movement periods, but oneimportant study has shown that fossil fuels kill twenty times the number of birds per unit of energy than wind turbines.178 Although wind farms cover large areas of land, the land beneath the turbines can still be used for agriculture and other purposes, meaning that the actual geographic footprint of wind generation is small. Wind farms have also been sited offshore, where wind speeds are often higher than they are over land.

Wind turbines' main disadvantages are that they are is non-dispatchable (electricity output must be consumed immediately) and that their production is intermittent. Like solar, this makes wind a poor choice for baseload power. Moreover, the highest wind speeds in many areas occur during off-peak hours, making wind slightly more difficult than solar to integrate into a grid power generation mix. Wind power is one of the cheapest of all renewable technologies. The capital cost of a wind farm has been estimated at RM 5,600,000 per MW, about 1/3 the capital cost of utility scale solar, and on par with that of coal. However, the per kWh cost of wind electricity depends on an installation's capacity factor, which depends in turn on the location's wind speeds and frequencies. For onshore turbines, wind speeds of more than 6 m/s at 80m height are considered most desirable for wind power development. For offshore turbines, which have higher capital and O&M costs, wind speeds of 8.6 m/s or more are typically required.179 The current average capacity factor for wind projects in the US is 41%.180 At that level of production, the levelized cost of wind power has been estimated at between RM 0.149-0.308/kWh.

As a result of these low costs, global capacity increased more than fourfold from 2000- 2006. Currently, the U.S., Germany, and Spain have the largest wind power capacities, ranging from 16,000-25,000 MW, and China and India are rapidly approaching these levels.181 The world's largest wind farm, located in the Southern U.S., has a peak capacity of 780 MW and covers 100,000 acres (400 km^2) [21].

Sabah literally means “land below the wind.” This epithet most likely refers to its position South of the typhoon belt, but many people used it to describe the low wind speeds over the state in general. Several studies confirm this anecdotal evidence:

1) A 1994 study by Universiti Kebangsaan Malaysia measured wind speeds and calculated wind power densities for Kota Kinabalu, Tawau, and Labuan [22]. None of the threelocations had wind speeds greater than 3 m/s or a wind power density of greater than 50W/m^2. As a result, the study classified thewind potential as a 3 on the NREL 1-7 scale, corresponding to a judgment that wind investment was not likely to be feasible.

2) Low-resolution wind speeds for any latitude and longitude in Sabah are available from the U.S. National Aeronautics and Space Agency [23]. Several spots were investigated and has suggested that these spots may experience higher-than-average wind speeds, including the site of the proposed coal plant, without finding any promising locations.

3) A 2003 study of wind speeds off the various Malaysian coasts at 80m height found wind speeds of 1.2-4.1 m/s throughout the year, too low for effective use of wind power [24]. Stronger winds occur during the Northeast and Southwest Monsoons, especially off the East Coast of Peninsular Malaysia and in certain areas off the coast of Sarawak and Sabah [25]. One region off the coast of Sabah, spanning 6-8° latitude and 114-116°longitude, was found to receive wind speeds exceeding 5mph during the northeast monsoon season (3 months) but falling between 1.6 and 4.4 mph for the rest of the year.

This is most likely not optimal for wind power [26]. Nevertheless, wind power may be commercially feasible in certain scattered locations throughout Sabah. In 2009, a private study was conducted of wind speeds in Kudat division, the most promising location for onshore wind in Sabah of which we are aware [27]. The study found wind speeds of 5 m/s all along the coast in Kudat district, and found wind speeds of up to 8 m/s on the ridge lines above the Kudat peninsula. It is possible to imagine wind farms of 10-20 MW being commercially feasible on these ridgelines.

As the study itself indicates, a great deal of further study is required before recommending these locations as commercially viable. Energy output is disproportionately higher at high wind speeds than low ones, meaning that average wind speeds do not fully capture a location's potential for wind power. Moreover, the variability of wind speeds would need to be observed over several years in order to reduce the uncertainty of any estimate of power output from a wind turbine. At the same time, at least some basic information about the distance of the most promising sites from existing road networks is required to estimate construction cost within a reasonable range. For those reasons, we do not consider it productive to report a Sabah specific levelized cost estimate for wind electricity at this time.

Malaysia experiences wind of strength 3-4m/s average annually. Hence the wind turbine already existing in the world market is not feasible economically to be implemented in Malaysia since it operates in the wind strength of 8-15m/s.

Chapter 5: Proposed Systems

5.1 Pulau Banggi Wind Resources

It is witohut doubt that Pulau Banggi has some good seasonal wind resources based on the feedbacks from the local community, the local authorities and the observations of visitors to the island. However the wind quantity is not substantial to warrant the setting of a full blown localised wind turbine system of 0.5 MW and more, who's role is to produce electrical energy and this is not sustainable and economical. The wind map indicate rarely the wind speed on the island is able to reach more than 2 m/s. The interest in Kudat and its coastal areas are also based on a NASA's wind chart, which indicated a pattern of consistent winds in the nothern tip of Sabah [28].

The proper wind map undertaking work must be done by professionals and it has to be done for a prolong duration which in the opinion of the researchers must exceed more than two years. Sadly to say, the UTM research team is unable to undertake this role as it requires consistant monitoring and frequent visits to the island by the team members with plenty of equipments put on site. The adequate wind data is to avoid preliminary project failure due to inadequacy of wind density information making the wind turbine redundant most of the time. Similar pilot wind power projects in the past (in a remote spot in Sabah) did not work as planned because of the lack of proper studies. Once the proper studies has been done, microscale modeling, high resolution colour wind speed and power density maps will be drawn up for the study region for final decision making. The wind map results will identify regions where wind turbines would function and those that are unlikely. The results of the microscale modeling will be use to undertake a pre-feasibility analysis to design a wind farm system at site that tally with the potential generation capacity.

Without a comprehensive data assessment on the potential it will be purely based on the work of the previous researchers. In this case, the work of a group of scientist from USM will be relied upon [29]. This group of scientists has mapped the wind data for the narrow window between Kudat and the Sulu Sea and has come up with mean speed for the offshore region of north east of Sabah to be between 2.6 to 2.9 m/s. From December till March, the wind speed reached a peak value of 4.3 m/s. With the exception of May (where wind speed is well below 1.5m/s), the rest exceed the 2m/s threshold. The direction of the wind is from the northeast and east quadrant during the northeast monsoon season and south and southwest quadrant during the southwest monsoon season.

However, based on the geographical locations of villages it was focussed that the village household units will no be more than 150. Based on this information the estimated requirement the energy demand would be 150 kW (1kW/household). At this junction it was decided that the hybrid system proposed for this project will not be more than 150 kW capacity.

5.2 The Hybrid Systems

Hybrid power systems use local renewable resource to provide power. Village hybrid power systems can range in size from small household systems (100 Wh/day) to the one with capability supplying to a whole area (10's MWh/day). They combine many technologies to provide reliable power that is tailored to the local resources and community. Potential components are PV, wind, micro-hydro, river-run hydro, biomass, batteries and conventional generators. Solar technology (PV) being a moderate investment and maintenance that leave the group to ponder three available energy options. Due to the nature of the community on the island, the survey conducted by the UTM research group indicates that currently the electrical energy requirements are only for home use and other daily needs.

Having taken into consideration of other aspects such as resources, and economic viability, the options which are suitable for the community in Pulau Banggi are derived as follows:

a) Option one: Micro-grid system Architecture

Small systems with demands up to 100 kWhr/day load (15 kW peak load). The systtem is characterized by the following features:

- Components consist of wind, PV, batteries and conventional generators
- Provide AC and potentially DC power
- Use of batteries to store renewable energy for use at night or low renewable times
- Generator used as backup power supply

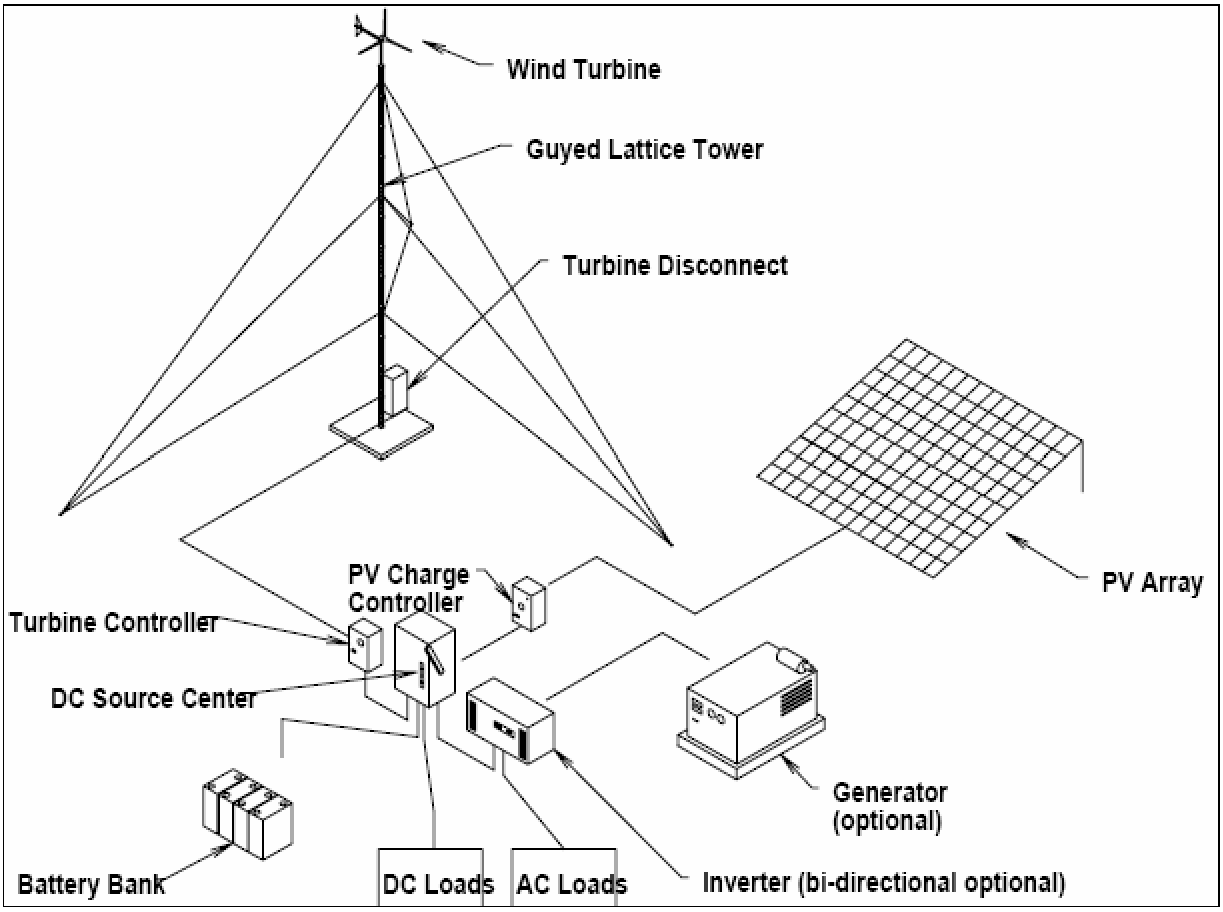


Figure 5.1: Illustration of the micro-grid hybrid system intended for the island.

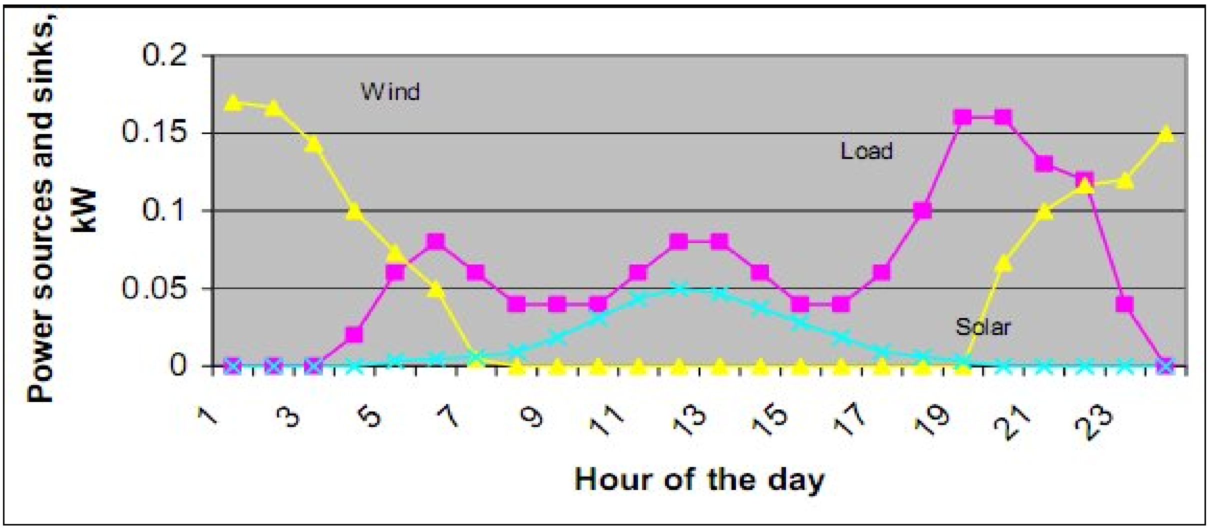


Figure 5.2: Typical energy profile for the hybrid system.

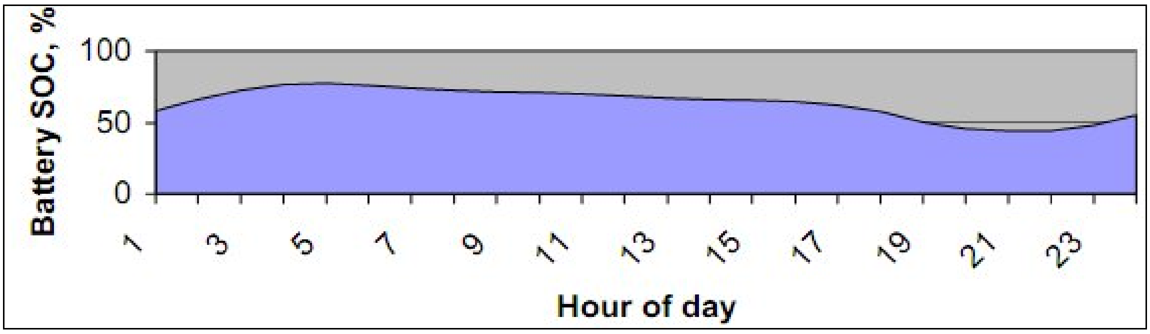


Figure 5.3: Typical state of charge (SOC) of the battey for the hybrid system.

Figure 5.2 shows a possible scenarios of the system behaviour due to wind and solar effect, the loaqd demand and the magnitude (Figure 5.3) to the state of charge for the battey bank.

b) Option two: Wind/Diesel with Short Term Storage

The second option will be to have a hybrid system that combines several wind turbines with diesel generator set with a storage system for just storing excess energy for a short period of time (refer Figure 5.4). The features of this option are breifly characterised as follows:

- Diesel used to provide power to system when the wind can not cover load.
- Battery used to fill short gaps in or to start diesel-generator sets

Figure 5.5 is a simulated performance of option two with three profiles representing wind (pink), demand (blue) and charging (grey).

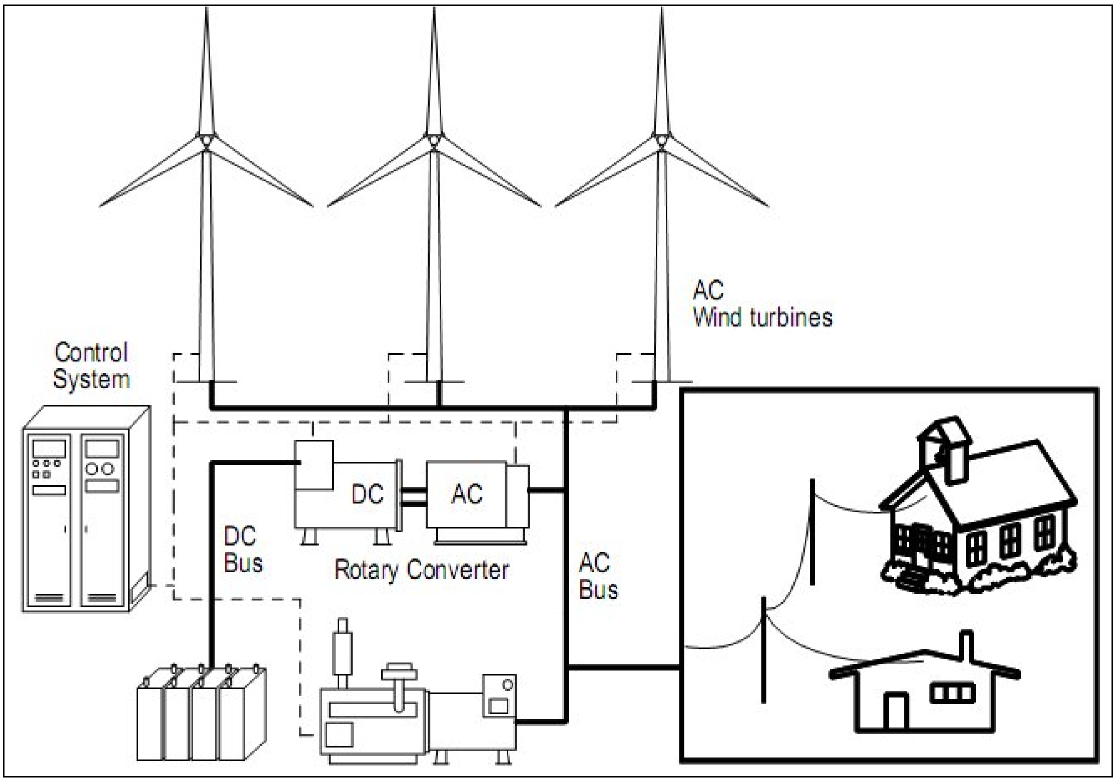


Figure 5.4: High penetration hybrid system with storage.

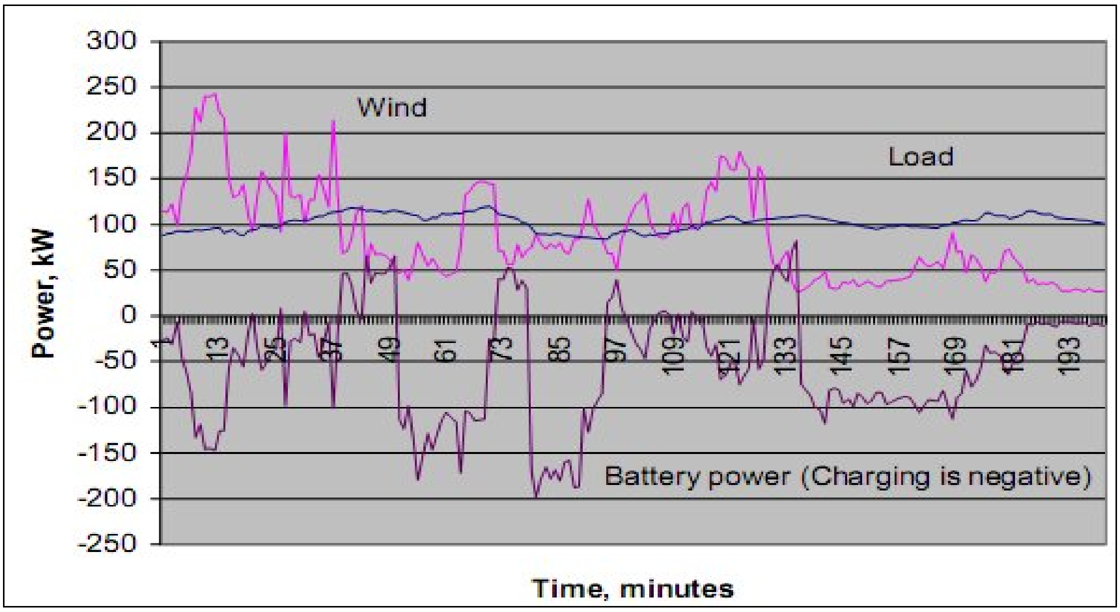


Figure 5.5: The power profiles for wind, charging and load of
a typical high penetration hybrid system.

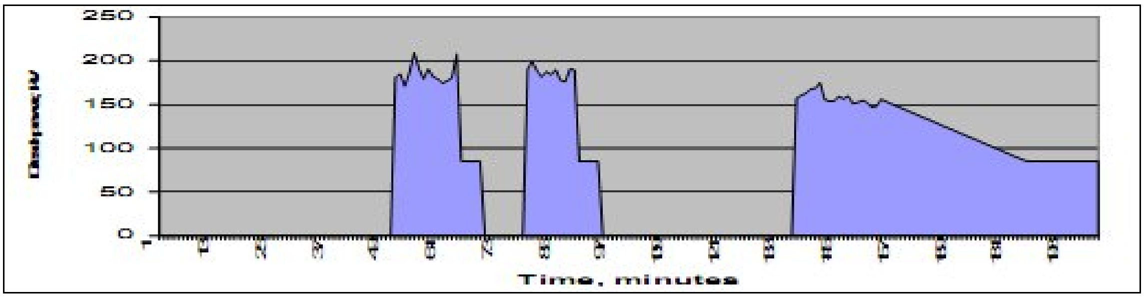


Figure 5.6: The state of charge of the battey system.

c) Option three: Wind Diesel without Storage

When the wind power is larger than the load by some margin - diesel is shut off.

- Frequency controlled by dump load
- Voltage controlled by condenser

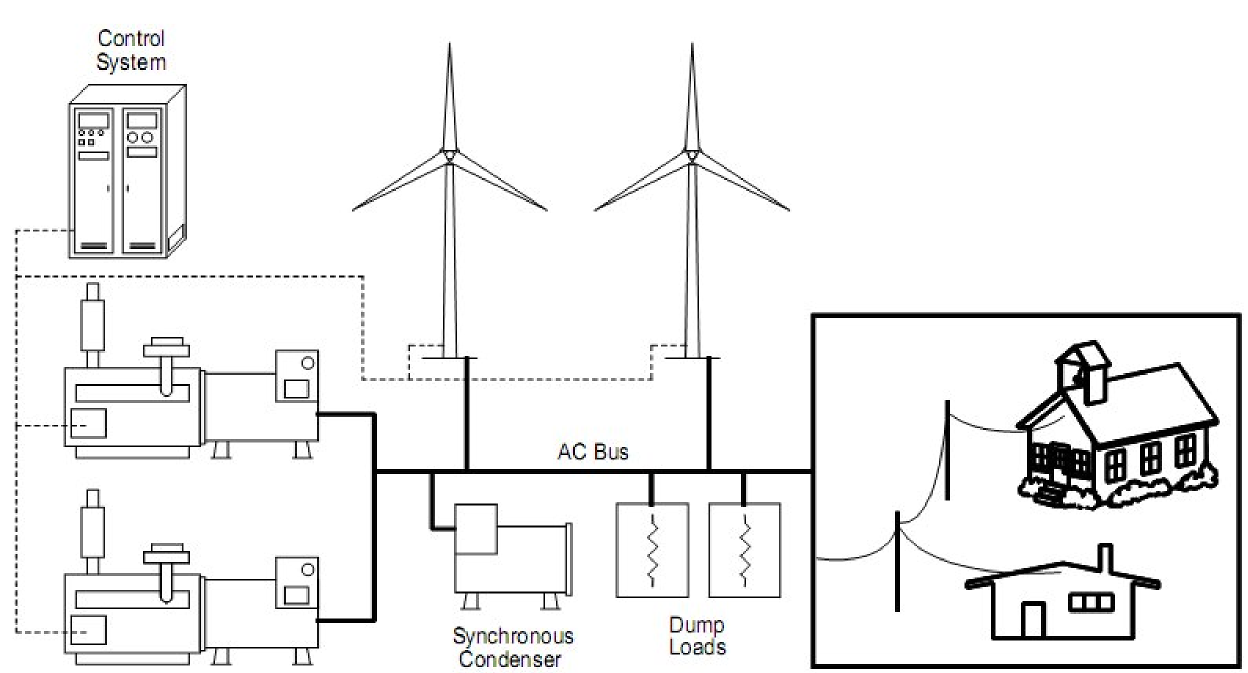


Figure 5.7: wind-diesel hybrid system without storage.

Figure 5.7 illustrates the proposal system which may consist of two wind turbines of the same rating riding on two generators with a form of dumping load bank which could be a heater for drying, or for any other application deem necessary for the need of the community. Figure 5.8 depicts the possible scenarios in which such a system will fit with the situation on the island.

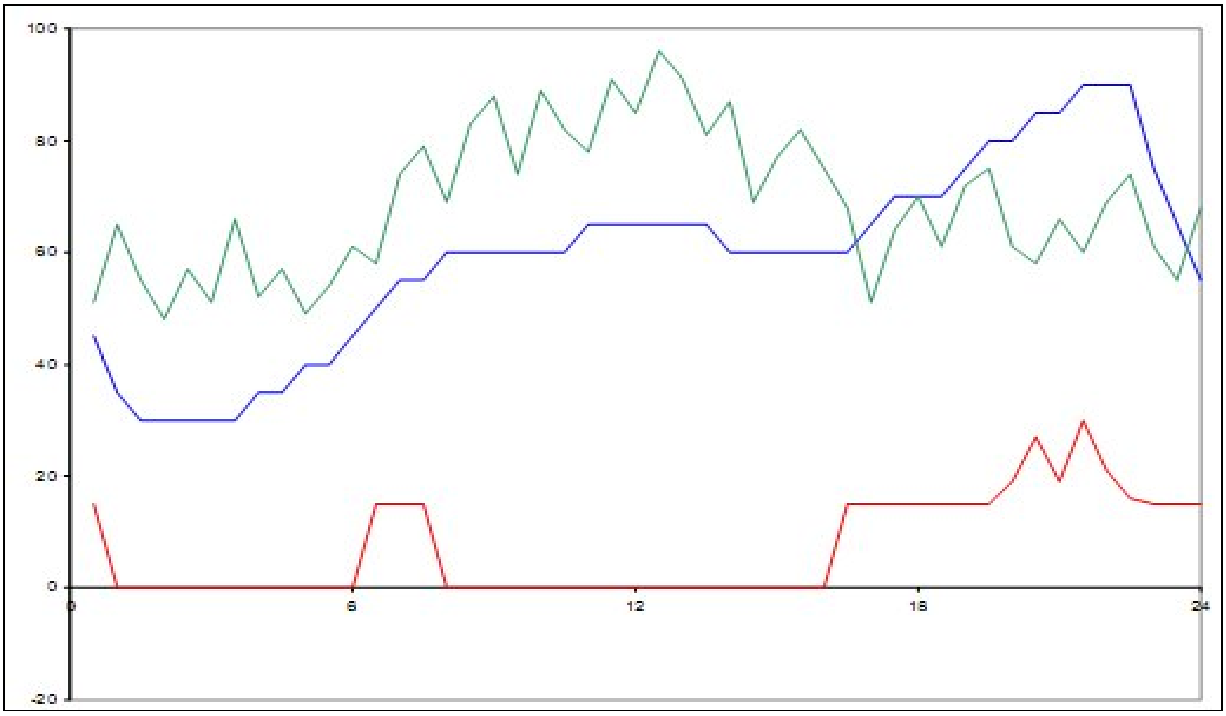
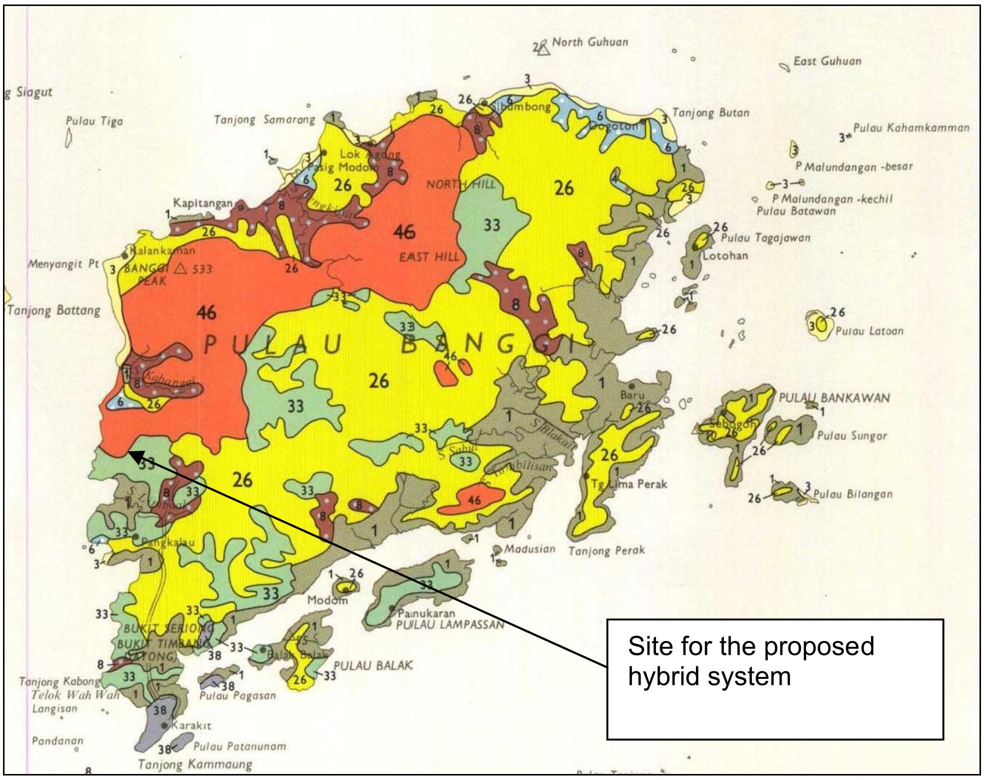


Figure 5.8: The performance characteristic of the wind-diesel hybrid (red is diesel, green is wind and blue is load)

The wind-diesel power systems are for systems with demands over ~ 100 kW peak load to many MWs. Based on an AC bus configurations. Batteries, if used will store power to cover short lulls in wind power. Both small and large renewable penetration designs available. It able to provide AC power as and when needed.

Figure 5.9 show the location of the hybrid system in the area known as kampung aur which is about 5 km away from the town of karakit.



Site for the proposed hybrid system

Figure 5.9: Map of Pulau Banggi, Sabah.

5.3 Biofuel for Diesel Generator Sets

Due to rather high cost of diesel fuel, the obvious option for the islanders is to look into the use of alternative fuel, which in this case, biodiesel fuels. The likeable choice will be coconut and palm oil to blend with diesel as this is increasingly viable, and will contribute towards a more competitive utility operation. Both of these commodity will be the likely source of income for the island [30].

A feasibility study on the use of low blends of filtered coconut oil in non-modified engines (in many third world and Pacific islands) have shown that short term savings can be achieved with relatively little investment. Many diesel generator set nowadays are very tolerance to the use of bio-diesel blends and have proven to be robust and durable. Other benefits will include the support of local agro-industries and an overall decrease in emissions.

5.4 Power Balancing Techniques

The following control strategies are required for a hybrid system involving the three mode of energy supplies:

1. Control wind generation:mechanical pitch control, electronic control, individual machine switching in multiple machine windfarms.
2. Dispatchable Loads: Installations of controllable incremental loads like resistance heating to consume extra power.
3. Load shedding where non-critical loads are temporarily shut off to quickly reduce system load.
4. Back-driving the diesel generator, a process where power is actually put into the generator to overcome the generator losses while keeping the generation running so that it can be loaded quickly. Installing systems, like block heaters, to allow quick starting of generators.
5. Installation of a synchronous condenser or rotary converter, which is used to produce reactive power
6. Installation of a capacitor bank to smooth out rapid power transients and partially correct the systems power factor

5.5 Summary of Proposal

The simple principle of a wind turbine -- using the wind to push blades that turn a generator shaft -- works at any scale and is simple enough to build especially for home use. The most complex part of building a wind turbine is shaping the blades to extract the maximum energy from the wind.

A horizontal axis wind turbine (HAWT) is by far the most preferred choice for a modern wind turbine. There are three blades that are attached to a central rotor, and they spin as the wind blows them. These blades are long and straight, curved slightly to catch the wind.

The choice out of this three proposals depends upon the i) cost of investment ii) operation and maintenance capabilities of the operator, iii) load demand. The task force (UTM research group) feels that option one will be ideal for very small community where demand may not exceed 100kWh/day. But for large village population of say more than 150 houses then the third option will be ideal but again cost will escalate. Option two will be for coomunity of anything between 20 to 150 houses.

Whatever the choice the horizontal wind turbine has been proposed to have the following features which are thought ideal and economical to operate. The number of wind turbine can be increased depending on the needs. The investor needs to juggle between the number of this type of wind turbine, generator and the arrays of photo voltaic.

Table 5.1 : Features of the proposed horizontal wind turbine.

Rated power	3000 W
Maximum power	4000 W
Rated Voltage	240 V
Generator	3-phase permanent magnet
Rotor Diameter	4 meter
Start-up wind	2 m/s
Survival wind	30 m/s
Rated rotor speed	200 rpm
Tower material	steel
Blade material	Fiberglass/composite
Number of blades	3 pieces
Weight (without tower)	400 kg
Tower height	10 m
Tower type	Free standing or wire guyed
Suggested battery capacity	12 V 200AH

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

The following conclusions are derived from this feasibility study:

1. A small-scale hybrid energy system is proposed. The proposed system is based on the data gathered from all sources, the site visits made and the initiatives made by both the Sabah and the federal governments on the future needs of Pulau Banggi. The system proposed is a demonstration prototype having a capacity of 150 kW. This will be sufficient for 100 to 150 households for the rural community of Pulau Banggi, Sabah. The hybrid system will consist of several nine (9) m tall three-bladed wind turbine (3 kW), a PV array of 20 kW and a generator set of 120 kW capacity with flexibility of using bio-diesel fuel to render the system economical and environmental-friendly.

2. The components of the proposed hybrid system can be largely outsourced within Malaysia. The wind turbine can be easily designed by the team but its integral components (17 of them) must be outsourced from local supplier. The two other harnessing sub-systems i.e. the PV arrays and the generator set(s) can be purchased locally. To undertake such a task of integrating many sub-system calls for the involvement of local company(s).

3. The estimated cost of the system is RM 700,000.00. This is based on the cost of producing the system alone locally at RM 4500.00 per kW. This is a modest figure which does not include the system integration work, labour, installation and others which could escalate to RM 900,000.00.

4. The location of the proposed hybrid system must be on a high ground without any obstruction to the wind flow. The location is at a place called Kampung Aur. The other reasons are due to i) locality ii) proximity to the main road, easy excess, and iii) near to community concentration.

5. The exploration on the use of bio-diesel fuels should be an attractive proposition for the setting up of the hybrid power generating system for rural community. In view of the agropolitan effort for Pulau Banggi where coconut and palm oil plantations are being proposed for the land redevelopment programme, the use of bio-fuel as a diesel extender will suit ideally to the concept of economical and environmental-friendly power generation system.

6.2 Recommendations for Future Work

Once the authorities/investor has decided to go ahead with this project, the following work will have to be embarked on:

1. Firstly, the engineering design leading to the fabrication of the small wind turbine with the specifications mentioned in Chapter 5 must be implemented. This can be done by giving the extra attentions on materials, aerodynamics, transmission, instrumentation, mechanical linkages, power electronics, and structural work.

2. Secondly is to draw up control architecture protocol based on the choice proposed in chapter 5. What this means is the programmable logic control of the hybrid energy system that is intelligent enough to automatically switches from one mode to the other depending on the climatic and weather conditions during the day..

3. Thirdly would be the choice of generator sets and the batteries needed for the system (if it need be),

4. Fourthly is to decide on the choice of the PV arrays and how to tie this unit to the wind turbine and the generator sets.

5. Fiftly is the setting up of an appropriate shelter, and parameter fences that will protect the integration of all the above elements into one cohesive hybrid energy system that will weather all conditions and enviornmental effect, knowing very well that this system is situated in the robust environment such as high moisture content and high temperature thoughout the year.

6. Finally is the connection to the gridline leading to the respective houses what will benefit from the production of the alternative energy through wind, solar and possibly biofuel-powered generator.

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