WIND DATA RELIABILITY IN PAKISTAN FOR WIND POWER GENERATION

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A Dissertation submitted in Partial Fulfillment of the Requirements for the degree of Doctor of Philosophy

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بسم الله الرحمن الرحيم

DEDICATION

To my Mother and Father

ABSTRACT

The exceptional wind regime of the coastal areas of Pakistan has attracted many national and international private investors. One of the major hurdles regarding realization of wind power is non-availability of historical wind data and the available wind data of the potential wind development areas gathered by Pakistan Meteorological Department (PMD) not being at international standards. In this situation, private sector was not able to cross the threshold of uncertainty when it came to invest their capital in a new sector. Wind data reliability becomes the most critical configuration item for the investors. To overcome this situation with the available set of information, that is the wind data gathered by PMD masts; an innovative concept of *"Wind Risk"* was introduced by the author. It is defined as the risk associated with the variability of wind speed because of unreliable data. The main theme of the concept is that, the "*Wind Risk*" shall be borne by the purchaser against the benchmark wind speeds calculated using wind data gathered by PMD for the life of the project to mitigate the risk of wind speed variability for investors and lenders. This has not been done anywhere else in the world before, as different concepts have been used to mitigate the wind speed variability risk. Most of the countries require investors to take the wind speed variability risk as a commercial risk. Investor then do the uncertainty analysis of the available set of wind data and normally uses higher probability of exceedance than P75 to cover the risk of wind variability. Some investors would take insurance cover to mitigate the risk. In all the cases the payment mechanism shall be take and pay where investor are simply be paid based on the energy calculated on the energy meter at the grid (energy price multiplied by the energy measured and delivered to the grid). Most of the countries in Europe and USA have their own wind atlas and wind data acceptable to investors and lenders. In these countries, most of the development occurred in the last two decades with respect to on-grid power from wind energy. China and India also uses take and pay mechanisms where investors take all the wind speed variability risks. However, they used different mechanisms to attract the investors like Chinese Government set specific targets for utilities with lots of fiscal incentives on local development to promote wind industry development. Similarly, accelerated depreciation in India to kick-start the wind projects using big giant organizations than directly requiring the investment from the private sector as an Independent Power Producers. The mechanism proposed by the author enables and attracts the direct investment from the national and international investors and lenders. A detailed study was done and analysis was done based on site visits and data collected from the masts installed by PMD and international IEC standard reliable wind masts in Gharo and Jhimpir. The study revealed that the masts installed by PMD was not observed as per the IEC standard and termed

as unreliable masts in the thesis. Comparisons have also been made between the data sets of reliable and unreliable masts. Author developed the benchmark wind speeds for the two regions in south of Pakistan, Gharo and Jhimpir. Wind Speed Benchmarks developed for these areas are based on the data collected by PMD using Gharo and Nooriabad met masts respectively. Power production from the wind power projects and the consequent energy payments will be governed by these benchmarks. Payment mechanism is laid down with formulae developed by the author that would govern the energy payments based on "*Wind Risk*" coverage.

The potential revenue lost for the investor in a scenario where wind farm is available but the grid is not available to take the energy from the wind farm is termed as Non Project Missed Volume (E_{MVy}). This is made integral part of the overall "*Wind Risk*" concept and a comprehensive protocol with formulae is developed to calculate Non-Project Missed Volume.

It is concluded that the whole mechanism proposed in this thesis for the use of "*Wind Risk*" concept may be considered for the fast track and sustainable development of wind energy in countries / areas with wind potential not supported by historical and International Standard on-site wind data and where it is difficult to attract investors using indirect policy incentives.

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*All praises are to Almighty **Allah**. First and foremost, I thank Allah.*

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List of Abbreviations

AEDB	Alternative Energy Development Board
AEP	Annual Energy Production
CSV	Cumulative Semi Varigram
DTU	Technical University of Denmark
$d_{MVE, avg}$	Weighted Average Duration of the Missed Volume Events
ED	Net Delivered Energy for the Period preceding the given month
E_{mv}	Missed Project Event
EPA	Energy Purchase Agreement
E_{pc}	Power Curve Energy
E_{MB}	Monthly Benchmark Energy for the preceding Month
$E_{monthly}$	Monthly Energy for the preceding Month
E_{reg}	Regular Energy for the preceding Month
E_{short}	Shortfall Energy for the preceding month
E_{sur}	The wind farm yield surplus
E_{bonus}	Bonus Energy for the Preceding Month
GoP	Government of Pakistan
GW	Giga Watt
IEC	International Electro Technical Commission
IWEA	International Wind Energy Association
km	Kilometer
IPPs	Independent Power Producers
P_{bonus}	Bonus Energy Payment for Bonus Energy for the preceding
PMD	Pakistan Meteorological Department
LPG	Liquid Petroleum Gas
MVEp	Missed Volume Event for the Period
MVE's	Number of Missed Volume
MW	Mega Watt
NEPRA	National Electric Power Regulatory Authority
NREL	National Renewable Energy Laboratories

NPV	Net Present Value
NT_{MVE}	Total wind turbines affected by Missed Volume Event
P_{short}	Shortfall Energy Payment for the preceding Month
P_{bonus}	Bonus Energy Payment for the Preceding month
SCADA	Supervisory Control and Data Acquisition
$SEEP_m$	Wind Farm Yield Surplus
SRD	Standard Regional Dependence
T	Tariff
T_{wtg}	Total Number of Installed Wind Turbines
T_{start}	Number of Minutes in Given Month

CHAPTER 1 : INTRODUCTION

1.1 Introduction

The electricity mix of Pakistan is heavily tilted towards thermal with 35% of total electricity being generated from imported oil as shown in **Figure 1.1** [1]. Any price hike of oil in the international market can potentially affect the electricity generation adversely. Now, Pakistan is encountering the worst electricity crises of its history resulting in extended load shedding to an extent, which impedes industrial growth and virtually suspends social life. The situation has further forced Government of Pakistan to take decisions like early market shutdown and power cutoff to industry thus affecting all business activities. At this time, it is nearly impossible for both consumer and government (circular debt issue) to bear the cost of electricity because of the existing oil based power projects.

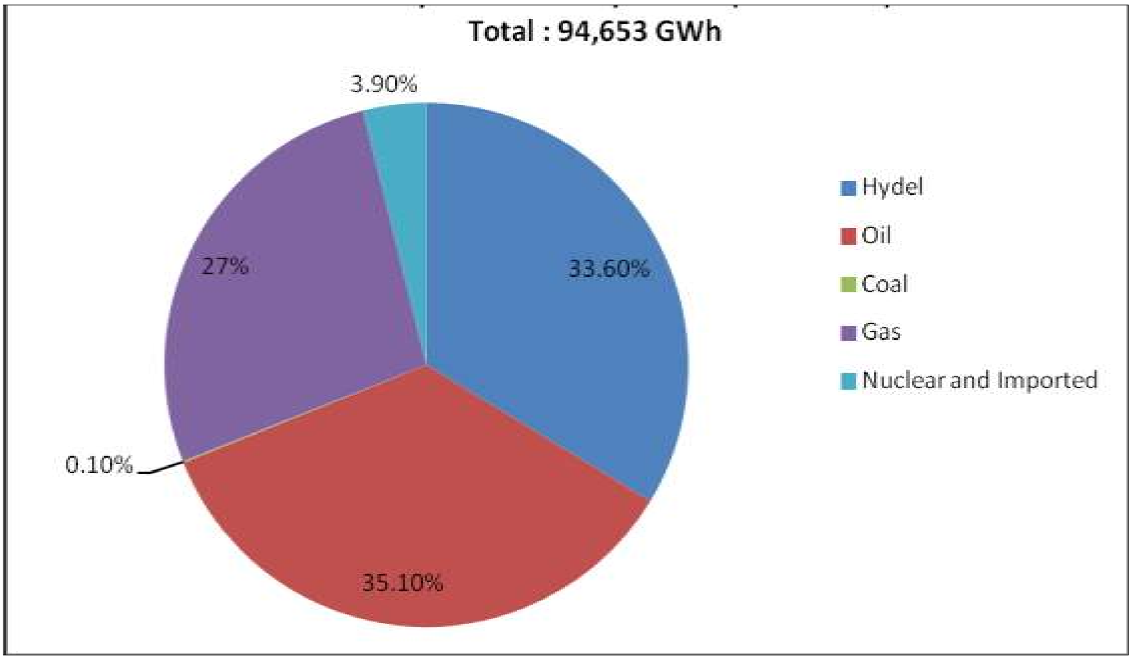


Figure 1.1: Primary Electricity Mix of Pakistan (2010-2011)

[Source: Pakistan Energy Yearbook, 2011, Ministry of Petroleum and Natural Resources, Government of Pakistan]

A cursory analysis of the situation and electricity mix of Pakistan reveals that the immense Renewable and Indigenous energy resources have been totally ignored by the policy makers and planners driving our energy sector. The energy plan 2030 of Government of Pakistan shows that the share of oil is going to be reduced in future as shown in **Figure 1.2.** However, no notable progress has been made in this direction since the initiation of this energy plan in 2005 [2]. An out of the box thinking to utilize our own indigenous resources like wind energy is required to surmount this power crises.

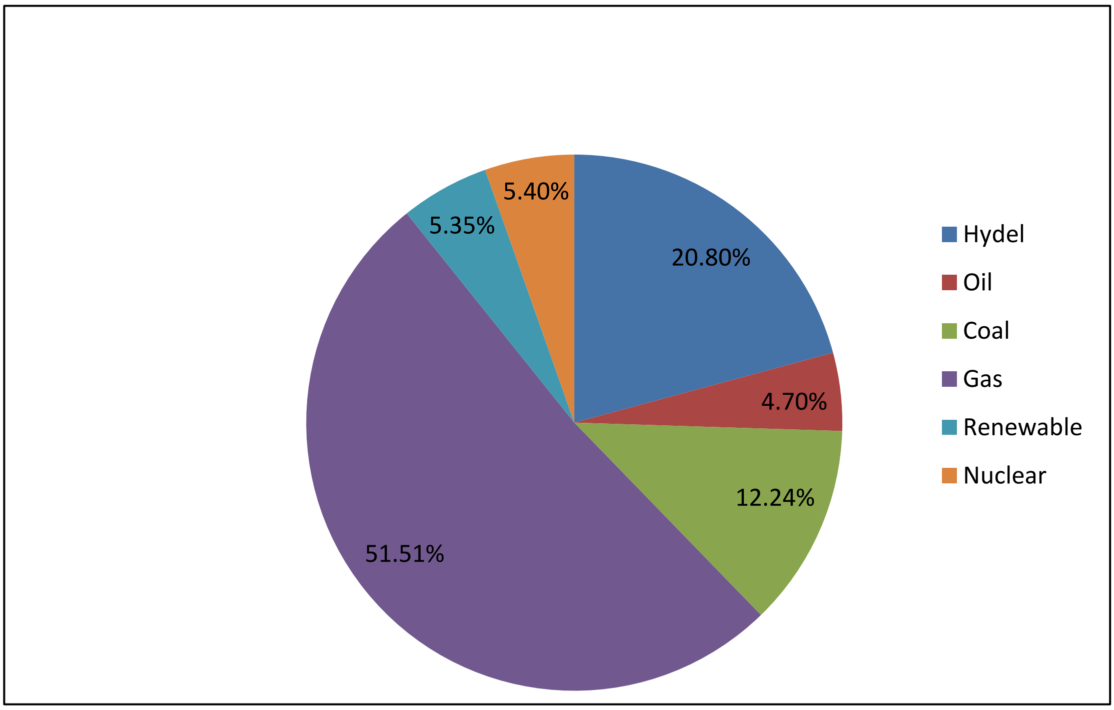


Figure 1.2: Power Generation Plan of Pakistan-2030

[Source: Energy Security Plan 2030, Planning Commission of Pakistan]

The development in renewable energy sources has gained a lot of interest globally. Wind Power industry is the fastest growing industry among other renewable energy technologies in the world. Electricity generation from wind turbines is now cost competitive with other electricity generating conventional sources. It also has other benefits over conventional sources with respect to sustainability and environment [2].

1.2 Wind Regime in Pakistan

Pakistan has 1046 km long coastline with very favorable wind conditions [3]. The flat coastal terrain makes it more suitable for power generation through wind. Surveys carried out in this coastal belt point towards a wind corridor stretching about 60 km along the coastline of Sindh province between the towns of Gharo to Keti-Bandar and more than 170 km deep inland towards Hyderabad shown in **Figure 1.3.**

Figure 1.3: Wind Corridors in Coastal Areas of Pakistan

[Source: AEDB: http://ww.aedb.org]

Wind energy potential from the same corridor is being harnessed in neighboring India's Gujrat region, where more than 700 MW wind energy has been installed [4].

The wind flow in this wind corridor from Gharo to Keti Bandar is very unidirectional for most part of the year, blowing from the sea towards the land. This phenomenon is due to the natural geographical setting of the region, with sea in the south and desert area in the northern part of the province. Wind is abundant in the summer months with peak winds during May to July and lower winds in the winter months from November to January.

1.3 Wind Mapping of the Coastal Belt of Pakistan

To estimate and capitalize the wind energy prospective in the coastal areas of Pakistan, Pakistan Meteorological Department (PMD) initiated a wind-mapping program where in 42 meteorological masts were installed in the coastal areas of the southern provinces of Sindh and Baluchistan as shown in **Figure 1.4** [3].

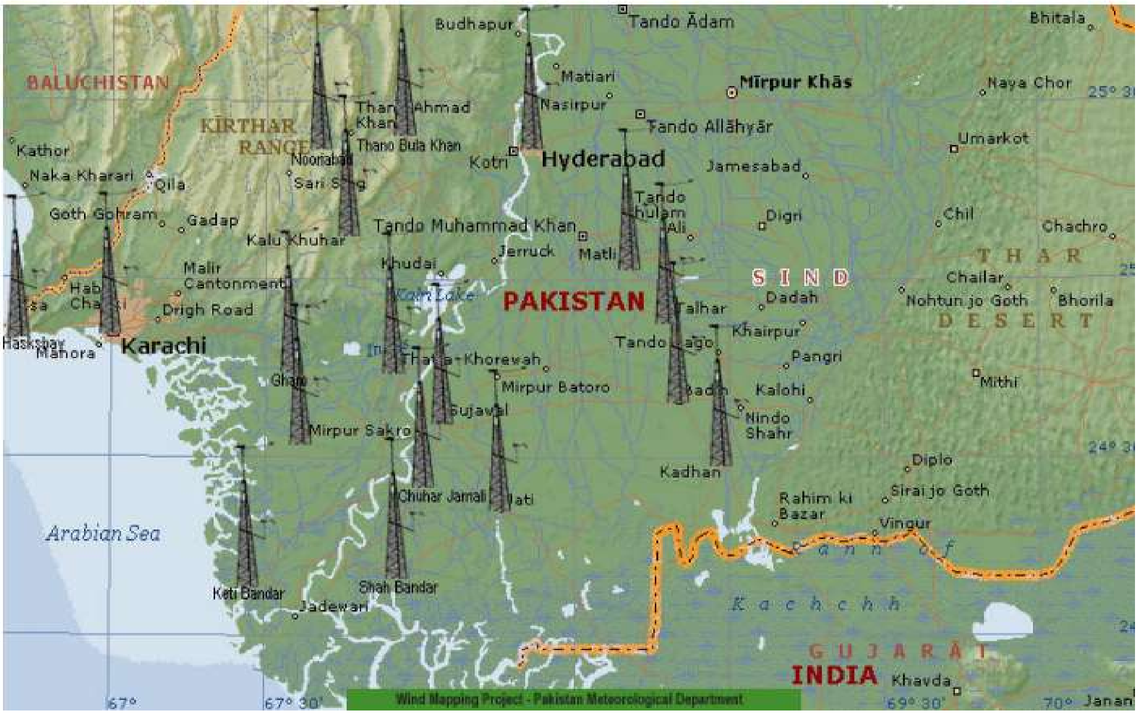


Figure 1.4: Wind Mapping Stations installed by Pakistan Meteorological Department (PMD)

[Source: PMD: http://ww.pmd.org.pk]

Anemometers were installed at the height of 10m and 30m in year 2002. Data logger developed locally had been installed to record data at each site.

These data loggers are recording, one-minute average wind speed at each level, One-minute average wind direction at 30 meters height, five-minute average temperature and 10-minute minimum and maximum wind speed at each levels.

Data analysis of the masts revealed that there is a wind strip in the coastal area of Sindh Province, which covers about 9700 km^2 with average wind speeds ranging from 6-8 m/s at height of 80 m above sea level. The estimated theoretical wind power installed potential of the area is 43000 MW and the realistic power installed potential is estimated to be about 11000 MW considering the area utilization limitation indicated by PMD [3,5].

The existence of wind power potential in the coastal areas of Pakistan, as assessed from the analysis of wind data measured from the meteorological masts of PMD, has been confirmed by the wind mapping of Pakistan by the National Renewable Energy Laboratories (USA) under the USAID assistance program in 2007. The map developed by NREL as shown in **Figure 1.5** [5].

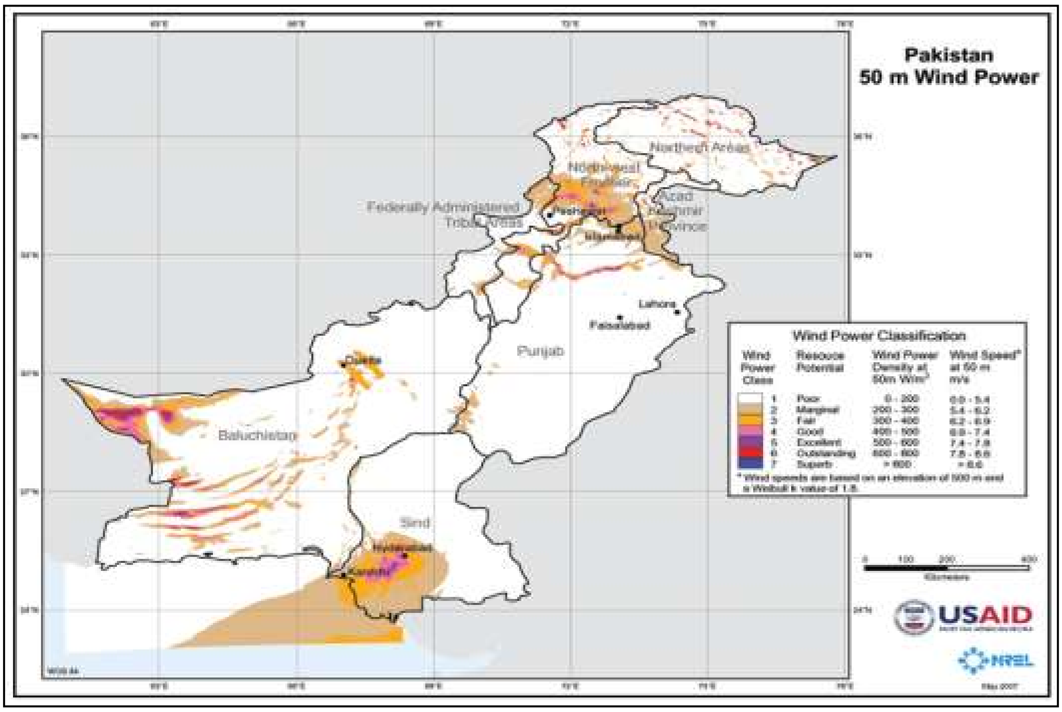


Figure 1.5: Wind Map of Pakistan developed by NREL and USAID

[Source: NREL, http://ww.nrel.gov]

This is developed by using computerized mapping approach of Geographic Information System (GIS) software in combination with numerical, empirical and analytical methods to produce One (01) km^2 high quality map. The map develop by NREL substantiates the presence of the wind corridor with very good wind speeds between Gharo to Keti Bandar This potential area has become the central area for the development of wind energy in Pakistan.

1.4 Problem Statement

One of the major barriers in realizing the wind potential in Pakistan and converting this potential into projects is the unavailability of long-term reliable wind data. Wind data is the key to predict power production for the life of the project. Only the power production analysis based on reliable wind data can be converted into bankable feasibility studies and projects. Tariff is calculated based on the power output of the wind farm. Importance of reliable wind data is the most critical configuration item as millions of dollars investment is made on the prediction of power output from the wind farm based on wind data. To understand the impact and importance of wind data; the cost of one 50 MW wind farm is around 135 Million US Dollars [6]. It means that if 1000 MWs are going to be installed in the country, the potential investment is of over 02 billion US Dollars.

There are many other factors involved in realizing the wind projects like investment climate of the country, regulatory framework, local trained human resource, availability of land in the wind potential areas, environmental considerations, grid availability and so on and so forth. However, the most fundamental and significant to initiate the process is the availability of reliable wind data. The typical life of a wind project is 20 years [7].

The unavailability or lack of reliable wind data remains the major barrier in the development of wind industry in Pakistan. Unreliable wind data increases the risk perceived by the project investors and lenders.

Lenders are the most critical as they provide around 70 percent of the project funding as non-recourse financing. It means that they pledge money based on future receivables from the project. This highlights the criticality of reliable wind data and acceptance of this by the lenders in developing wind projects in any country.

The risk perception is very high in case of unreliability of wind data, which in turn predict wrong output numbers from the wind farm and refrain investors and lenders to invest in the country [8].

When it comes to Pakistan, reliability of the wind data recorded by PMD masts was not up to the standard where it could be considered as bankable wind data. The author visited the masts, found that the wind data is not reliable due to non-conformity of equipments, and sub standard installation arrangement with respect to international standard best practices for collecting wind data. The recommendations written in the International Electro Technical Commission (IEC) standard 61400-12-1 [9] for installation of wind masts and international best practices were not followed while erecting the meteorological masts and installing sensors on the masts. The masts were installed at places having buildings or other structures close by, which may obstruct the free flowing wind streams, thus contributing to the level of uncertainty in measurement. This becomes the serious concern among investors and raised questions on the reliability of the wind data.

The development of wind power projects requires a detailed assessment of the wind regime of the area under consideration. The international practice is to analyze historical i.e.10 to 20 years wind data with at least one year of on-site data, recorded according to international standards IEC 61400-12-1, for the purpose of establishment of wind regime of that area which is required for estimating the power output from the wind farms. The site-specific wind data correlated with the historical wind data of that region becomes the basis of production estimation for the wind power project. The analysis of long-term wind data helps in predicting more reliable annual wind characteristics and wind speed averages resulting in reduced deviations in estimated energy production.

This is an important factor for making wind power projects bankable. The long-term wind data serves the purpose of risk mitigation from the lenders point of view. Data spanning short periods or less reliable wind data increases the risk factor on the estimated energy production, which in turn increases Lender's risk perception of the project due to unreliable payment streams.

In addition to that, questions have been raised on the reliability of long term wind data collected at airports and other met stations in the south of Pakistan as manual entries were made in collecting the data. That data was only collected at three different times of the day [3].

1.5 Objectives of the Research

A. The **primary objective** of the research is to devise a mechanism to overcome the issue of unreliability of the wind data in South of Pakistan for the fast track development of wind energy.

B. Following are the **secondary objectives** of the research:

1. Baseline analysis of the existing wind masts installed by the PMD in south of Pakistan in Sindh Province to highlight variances with respect to the international standard and best practices.

2. Analysis of three site-specific wind masts installed by the private investors claimed to be as per the international standard in the same region.

3. To develop a mechanism to immune the investors from the unavailability of the grid when they are available to deliver the energy because of the weak grid network in south of Pakistan for the fast track development of wind energy.

4. Translate the developed mechanism into the contractual agreements between the Seller and Purchaser like Energy Purchase Agreement.

1.6 Research Outline

Chapter-1 "Introduction" reflects the relationship between the current energy crises and potential of wind power in Pakistan. This chapter elaborates the problem statement of the thesis and describes the objectives of the thesis.

Chapter-2 "Literature Review" describes the history and overview of previous work done nationally and internationally related to this PhD thesis. It includes the international and the recent global trends of wind industry. This chapter analyzes previous researches on wind resource assessment, wind power intermittency, policies and software used in the wind industry. It also covers the emergence of wind power program in Pakistan and describes various stages of wind industry development in the country.

In **Chapter-3 "Unreliability and Reliability of Wind Data – Factors, Analysis and Comparison",** baseline data collection and analysis carried out during site visits of the reliable wind masts and unreliable wind masts installed are discussed. The author visited two masts installed by Government of Pakistan in Nooriabad and Gharo, which were not installed as per international standards. Two other masts installed by private investors "Green Power" and "Zorlu Enerji" were also visited which were installed as per IEC standards. The author visited all four masts and investigated the differences between the IEC standard mast and the unreliable masts in terms of instrumentation, quality and installtions. Author gathered the wind data for all four masts for the further analysis and investigation of effect of unreliable mast on the wind data. Wind data analysis has been carried out for both unreliable wind mast and reliable wind mast. The author select one unreliable mast data i.e. Nooriabd and the other IEC standard mast data that is of Zorlu Enerji. The author analyzed the wind data using WAsP software and results are drawn for monthly wind speeds.

After baseline data collection, analysis, and comparison of unreliable and reliable data, it is recognized that the long-term historical wind data is not available. Moreover, the medium term data is not reliable in a sense of planning commercial projects where huge investments are involved. Keeping all sensitive consideration in view and the crucial need of wind power in Pakistan, a concept of "*Wind Risk*" is introduced by the author which is explained in Chapter-4.

Chapter-4 "Proposed Methodology to Mitigate Risks Associated with Unreliable Wind Masts". Benchmark wind speeds on which Government of Pakistan would bear the "*Wind Risk*" has been developed for Gharo and Nooriabad mast data considering lowest values of monthly wind speeds. To validate the benchmark wind speeds, a comparison is made with vestas turbine with micrositing on same assumed lands. Annual Energy Production (AEP) is calculated with both unreliable and reliable met data. It was found from the comparison that AEP and capacity factor is at lower end with unreliable wind data as compared to the AEP and capacity factor of reliable wind data.

Further to this, a methodology is also formulated for translation of this concept into legal contractual agreements between power seller and purchaser. Energy Payment mechanism and formulas are defined in the thesis and verified. Formulas are also developed by the author for Non Project Missed Volume (E_{MVy}) and wind measuring protocols, as to successfully implement the concept in real life.

Chapter-5 "Results and Discussions" presents the results of the methodology and discussion with respect to the objectives of the thesis.

Chapter-6 "Conclusion and Recommendations" finally presents the conclusion of the thesis and recommendations for future work.

Annexure-I "Examples" is made part of thesis, which elaborates the Energy Payment Calculations for Non Project Missed Volume with the help of examples.

Annexure-II "Certificate from Government of Pakistan" as an evidence to support the work originality done by the author and proof of acceptance of *"Wind Risk"* concept by Government of Pakistan.

CHAPTER 2 : LITERATURE SURVEY

2.1 History and Emergence of Wind Power Technology

Since the industrial revolution thermal energy from coal, oil and gas are the key sources to generate electricity. However, the developed world has serious concerns now in using these sources because of the climate change issues. In addition to that, these sources are depleting quickly because of the increasing energy demand. This has put renewable energies like wind being non-exhaustible and environment friendly on the front.

Mankind is using wind power for the last 3000 years. Its use for electricity generation started almost 120 years ago. The technology of wind power gained acceptance in the market during 1970s oil crisis, but did not gain attention afterwards for many years [11]

During the first decade of the twentieth century, incentive policies were introduced by many countries to develop wind industry market. With the introduction of such policy incentives initiated in many countries, the wind market progressed rapidly, and wind technology brought a remarkable energy revolution in many countries. Denmark was a pioneer country in developing commercial wind power during the 1970s, and today Danish manufacturers such as Vestas and Siemens are producing almost 50% of the wind turbines around the world. Wind power provided 18.9% of electricity production and 24.1% of generation capacity in Denmark in 2008. In 2012, the Danish government adopted a plan to increase the share of electricity production from wind to 50% by 2020. Germany and USA are the countries to develop wind technology, after which many countries like China, India and Spain have made considerable efforts in developing wind industry [12]. It is projected that wind energy will accomplish 5% of the world's energy demand by year 2020 which is around 1 % as of year 2011 [13].

Dennis et al. [13] in their review paper on wind energy development and its environmental impact gives details of wind technology development in different countries. According to them, the annual generation from wind power has been growing with an average of 30% in the world. In 2010, China superseded US and became the top wind power producer in the world with total generation of 42.3GW, adding 16.5GW only in 2010 that is sixty four percent (64%) increase over 2009. Chinese wind power market is looking to achieve the milestone to produce 90 GW by 2015 and 200 GW by 2020. The success of wind technology in China lies in the development of in house technical systems and turbine technology, political will and government support [15].

Germany and Spain have been the pioneering countries to develop wind industry market in last fifteen (15) years and continued a stable growth of wind energy. Germany is still a top wind power producer in Europe with its total installed wind of 29.075 GW in year 2011. Germany met its 9.3% of the electricity demand from wind energy by the end of year 2011. Due to tremendous wind industry growth in the country, Germany is able to generate job opportunities for around 100,000 people. It is anticipated by German Wind Energy Association that the country would achieve 45 GW of onshore and 10 GW of offshore wind by 2020 [16].

After Germany, Spain has maintained its second place in Europe even after financial crises faced by the country in 2010. Spain has added 1.5 GW in 2011, reaching the total installations up to 20.7 GW . The year 2010 was also the blessed year of Spain in a sense that wind power produced 16.6 % for the total net consumption due to high blown winds throughout the year [17].

India shows continuing growth trends after development of renewable energy policies in 2003. India installed 2.1 GW in 2010, reaching 13.1 GW at the end of 2010 and got fifth place in the World [18].

According to International Wind Energy Association (IWAE), the Indian market has been a well-established market and has shown steady and stable growth since 2008. Top ten countries with Highest Growth Rates in Wind industry are shown in **Figure2.1.**

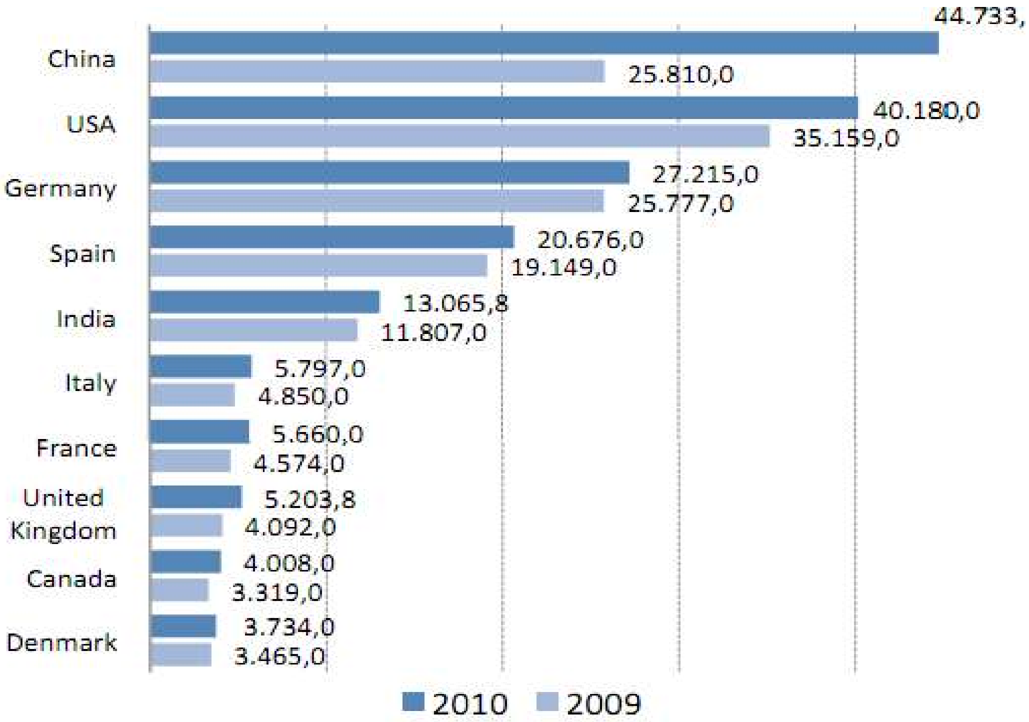


Figure 2.1: Top Ten Countries with Highest Grown Rates in Wind Industry
[Source: Global Wind Energy Council; http://www.gwec.net]

Wind industry worldwide has been dynamically growing and has shown continued steady growth particularly from the year 2001. The total global installed capacity of wind power has become 121,188 MW after 59,024 MW in 2005, 74,151 MW in 2006, and 93,927 MW in 2007 and reached up to 240,000 MW by end of year 2011 as indicated in **Figure 2.2.**

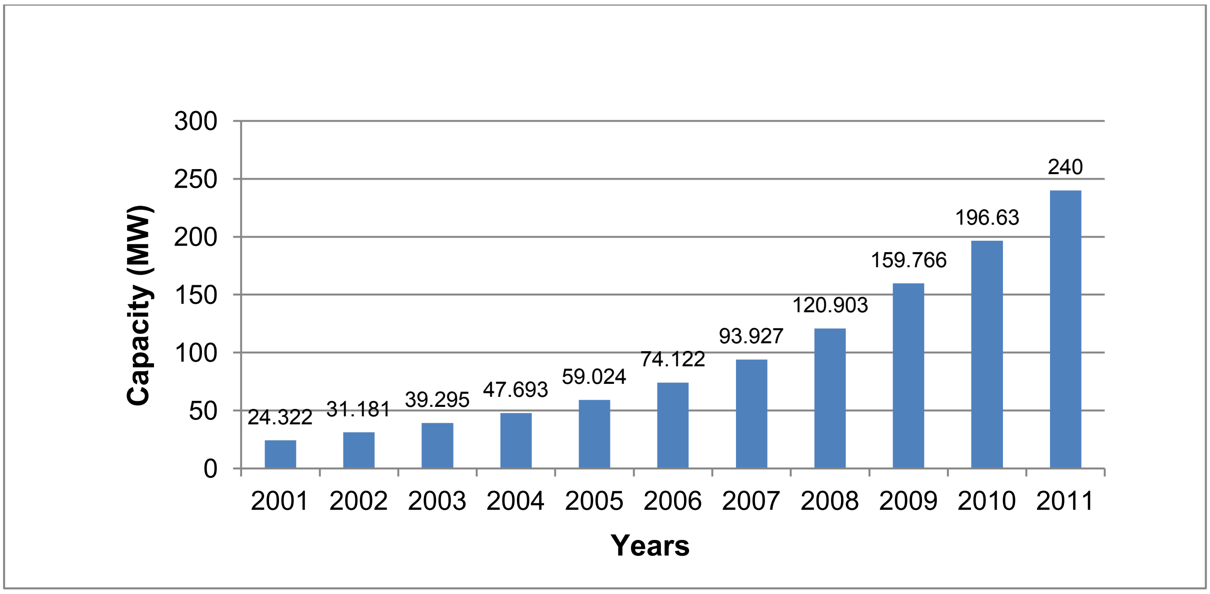


Figure 2.2: World Total Installed Capacity in MW
[Source: Global Wind Energy Council; http://www.gwec.net]

The overall revenues generated from wind industry has reached 40 billion EUR in the year 2008. With the robust growth of wind industry in China and India with total generation of 24, 439 MW, the countries are real source of inspiration for developing countries for development of wind industry [19].

2.2 Climate Change and Wind Technology

The expansion of wind energy in the world is bringing a positive impact to overcome the issues related to climate change. However, many of the researchers have revealed that there are few negative impacts of the wind energy industry, which must be considered, while developing wind power projects. However, the accepted fact worldwide is the sustainability of environment due to wind energy growth. Pryor et al. [20] reviewed the impacts of climate change on wind energy. According to him, geographic distributions of wind resource may change due to change in global climate. He explained that these climatic changes might alter the wind development situations in different regions of the world. Some regions may be benefited from wind energy development and some regions may be negatively impacted.

He revealed the fact that Global and Regional Climate models are not providing latest information on historical trends of wind climate. There is a huge variation found in the results of different Global and Regional climate models used in the wind and climate data analysis. He referred that 15 % change in the current inter-annual variability of Europe and North America calculated by the researchers during the present century is unlikely which shows that the climatic models used for the wind and climate analysis for the wind power development are not up to date and further research need to be done.

Wind Power technology is preferred over thermal and nuclear power generation due to the reason that wind power does not emit any greenhouse gases and is sustainable technology. However, there are several debates on noise, shadow and visual impacts of wind turbines generating from wind farms. Pedersen [21] has explored the relationship between the sound pressure levels of wind turbines and neighbors' well-being, showing that stress symptoms such as headaches appeared in those who were annoyed by the presence of wind turbines.

2.3 Wind Risk & Uncertainty Analysis

Wind energy played crucial role in helping countries to achieve energy security and to hit their carbon emission reduction targets. There are various technical and financial risks associated with the wind resource. According to World Wind Energy Association, the most critical is the wind intermittency and uncertainty.

Wind is often intermittent energy resource because these sources are uncontrollable and variable in normal operational conditions as compared to conventional fossil fuels. Uncertainty in wind speed is typically calculated as part of the wind resource assessment where statistical methods are used to predict the probability distribution of yields. The more uncertainty, the more likely the actual yields may differ from the yield estimate. It's usually due to a variety of things, such as the variability in wind speed and equipment performance.

The literature concerning wind speed uncertainty can be divided for instance into literature focusing on uncertainty in wind energy output and on economic profitability. With respect to wind speed uncertainty in wind energy output, Kwon [22] has elaborated a numerical procedure for evaluating the uncertainty caused by wind variability and power performance using probability models in order to assess the risk of power output deviations. He conducted a case study analysis to show that the standard deviation of the annual energy output normalized by the average value of power output is approximately 11 %, which can cause investments to be unprofitable.

Tindal et al. [23] have compared the predicted annual power production with the actual power production. Their dataset included 510 wind farms across Europe and the US. They showed that the actual wind power output is 93.3% of the predicted wind power output. According to the authors, a major reason for this deviation is the rather poor quality of wind speed measurements, which have been conducted before the installation of wind turbines. Thereby, the economic potential and profitability have been identified by applying traditional methods of financial analysis such as the Net Present Value approach, the Internal Rate of Return approach, or the Life Cycle Cost Analysis approach. In most of the countries, wind speed uncertainties are covered through improvement in wind speed forecasting models, which significantly reduced the cost associated risks with wind intermittency.

The issue of unreliable wind data was not raised in Europe and USA where most of the development occurred in the last two decades with respect to on-grid power from wind energy. They have the historical wind data acceptable to lenders as well as most of the European countries have their own wind atlas [24]. China and India in the last decade used other mechanisms to develop wind energy. China set specific targets to utilities in with lots of fiscal incentives on local development. Similarly accelerated depreciation in India to kick start the wind projects using big giant organizations than directly requiring the investment from the private sector as an Independent Power Producers helped to promote wind industry on large scale..

In India, Ministry of New and Renewable Energy (MNRE) has driven 70 % of the wind industry by generously and relatively risk free tax-break, accelerated depreciation (AD). AD is a financial mechanism that speeds up the depreciation in value of wind projects in the financial year after project commissioning, meaning significant reduction in tax liability. Until April 2012, investors were entitled under AD to claim 80% of the cost of the project equipment as expenses, paying no tax on this amount.

2.4 Wind Resource Assessment

Wind resource assessment along with parameters of wind such as topography, wind speed, wind direction and temperature are very critical factors to be measured for successful operations of wind technology. A brief literature review related to wind resource assessment is given.

Kocak Kasim focused on the importance of steady wind speeds, which is one critical factor in achieving constant energy production numbers [25]. Wood researched on the relationship between tower height and wind shear by using power law and algorithmic law. He concluded that wind shear in villages and suburban areas increases with the increase in tower optimum height [26].

Ozerdem et al. [27] present a case study of wind farm feasibility in Izmir, Turkey. In technical part of this study, wind speed, wind direction, and temperature measurements are taken to assess the potential of wind in the area. For economical consideration, three different scenarios namely, auto producer, auto producer group, and independent power producer (IPP) cases, are investigated and compared with respect to Net Present Value (NPV), internal rate of return (IRR), and payback period (PBP) criteria. It is concluded that, generating cost per kWh will be less, if larger capacities of wind farm will be installed as cost to production ratio in bigger wind turbines is low.

The wind power project will be financially viable, if the annual mean wind speed of a particular site is 20km/h at a hub height of 30m and power density of 150W/m^2. Wind energy potential of Grenada (West Indies) was analyzed by Weisser using Weibull density function based on historical data of mean hourly wind velocity [28].

Lambert et al. [29] provide the analysis of complete wind mast instrumentation and analysis of lattice masts and its relation to wind speed and direction and impacts of structural stresses in repaired joints. This paper provides full-scale instrumentation and analysis of tall-guyed lattice masts to correlate wind speed and direction with structural stresses, particularly in welds. It outlines a method of predicting residual fatigue life from past meteorological records, where regular inspection is difficult. Salim et al. [30] gave a probabilistic model for energy resource potential at two sites; analyze the relationship between equipment failure and the intermittent nature of the wind resource.

Zekai and Ahmet [31] determine the regional patterns of wind potential along the western Aegean Sea coastal part of Turkey using a Cumulative Semi-Varigram (CSV) model. This model is a unique model that provides indications about regional variations along any direction. The CSV technique provides the radius of influence for wind velocity and Weibull distribution parameters. The dimensionless standard regional dependence (SRD) functions are obtained from the sample CSV, which has been used to make simple regional predictions for the wind energy or wind velocity distribution parameters

Another research study was conducted on the statistical features of the wind at Oran. Torre et al. [32] preferred Markovian model for analyzing wind speed time series in Corsica region because a Markov chain seems to be more precise and accurate. Feijoo et al. [33] proposed two methods to assess the effect of a large scale wind farm with multiple wind turbines. He used Monte Carlo wind speed replication of different wind farms where measurements of average values and correlation are included.

Sfetses [34] analyzed the mean hourly wind speed data-forecasting using time series analysis. Aksoy et al. [35] gave the concept of artificial data generation techniques, which can be used for the areas where long wind speed data were required. In this study, idea of wind speed data generation scheme is introduced which is based on wavelet transformation is introduced and compared with the existing wind speed generation methods. Many researchers have worked out the analysis of time series wind data required for wind resource assessment.

According to Lalas [36], the available wind data for resource assessment must include mean wind speed on monthly basis, duration curves, persistence, wind rose, power spectra of wind speed, and data with respect to variation of height. The data should be collected for at least ten (10) year period to access the exact potential of wind on site for the development of mega scale multiple wind farms in the area [37]. However Frandsen et al [38] claims that a one (01) year period of wind measurement is reasonable to assess the potential of wind farm on a specific site including a percentage uncertainty of 5% to 15%.

2.5 Wind Power Forecasting Model

Reliability of wind speed has an impact on Annual Energy output, in turn an effect on the project costs, and ultimate benefits of a project. According to Guo et al. [39] wind data gathered from field may be incomplete or unreliable; therefore, it needs more general mathematical and algorithms models to solve the problem.

Wind power production from wind turbines is directly linked with wind speed [40]. Reliability of wind turbine system depends upon performance of wind turbine components under specific environment, manufacturing process, handling, and aging process. Fole et al. [41] gave in depth knowledge of present methods and advances in wind power predictions and forecasting. In general, precise and accurate wind power prediction decreases the financial and technical risk due to uncertainty of wind power production for all electricity market stakeholders. Wang et al.[42] compared different wind power models such as Wind Power Management System (WPMS), Wind Power Prediction Tool (WPPT), Prediktor, ARMINES for short term forecasts for the power output of onshore and offshore wind farm, Previento for operational wind power prediction system, Wind Power Forecasting System (WPFS) Ver1.0 etc and emphasis was given on accuracy of prediction models and the source of error. No forecasting model of them can be perfect in any condition, however these are effective tool to maximize the power captured thus increasing the reliability of wind power of wind farm [43].

2.6 Wind Speed Distribution Models.

Analysis of long-term wind data is critical for the estimation of wind energy potential and energy yield estimates. Investigating the Wind speed distribution is one critical task for this purpose. Junyi et al. [44] evaluates probability density functions for the wind speed data of five representative sites of North Dakota. Besides other practiced Weibull and Rayleigh distributions, Junyi also include other distributions such as gamma, lognormal, inverse Gaussian, and maximum entropy principle (MEP) derived probability density functions (PDFs). Six goodness-of-fit (GOF) statistics are used to establish the appropriate distributions for the wind speed data for each site. It is found that no particular distribution outperforms others for all five sites, while Rayleigh distribution performs poorly for most of the sites. Similar to other models, the performances of MEP-derived PDFs in fitting wind speed data varies from site to site.

The wind speeds distribution is important for design of wind farms, wind power generators, and agricultural applications. Various factors have to be taken into consideration in identifying sites suitable for the installation of wind turbine generators (WTG). The feasibility study must consider important factors such as wind speed, the potential energy from the wind, the generator type, and grid connectivity [45]. Wind power generation primarily depends upon wind speed, which can be influenced by obstacle and terrain. It also varies with height, so the unsystematic character of wind is significantly influencing the annual production estimates of wind farm. Therefore, reliability of wind power is not satisfactory because it cannot supply steady electricity to power system. Therefore, when the wind power penetration (i.e. proportion of wind power in a power system) grows, the power system operation will be affected [46].

2.7 Wind Technology Software

With the growth of wind farm technology worldwide, the complexities of wind farm placement become more demanding. There are various wind resource assessment software available in the market. Below are given the brief details of different software packages and their working models and benefits;

The Wind Atlas Analysis and Application Program (WAsP) is a PC-program for horizontal and vertical extrapolation of wind data. The program contains a complete set of models to calculate the effects on the wind of sheltering obstacles, surface roughness changes and terrain height variations. The analysis part consists of a transformation of an observed wind climate (speed and direction distributions) to a wind atlas data set. The wind atlas data set can subsequently be applied for estimation of the wind climate and wind power potential, as well as for micro-siting of specific wind turbines. It also includes WAsP Climate Analyst tool, the WAsP Map Editor tool, the WAsP Turbine Editor tool, the Air Density Calculator and various scripting tools. The same WAsP software is used for the wind data analysis and comparison wind data and Annual Energy Production (AEP) of unreliable and reliable wind masts in the Chapter-3 and Chapter-4.

WAsP is user-friendly tool to accommodate the data for the wind power plant production estimation. Data received from the data logger is imported into WAsP. WasP has built-in module to calculate wind atlas. Wind atlas includes calculated time-series of wind measurements to provide a statistical summary of the observed, site-specific wind climate.

In a wind atlas, data set of the wind observations are 'cleaned' with respect to site-specific conditions. The wind atlas data sets are site-independent and the wind distributions have been reduced to standard conditions. Standard conditions for the wind atlas are related to wind profile, calculated wind classes, calculated weibull distributions for the shape and scale parameters.

Flow Modeling technique is used in the WAsP to get the wind energy at a resolution of few meters to get near to the actual production estimates. In this model, some linearized form of fluid flow equation and the MS Micro Model is used [44].

CFD modeling has been used in the software named WindSim, but the model remains unsuccessful due to various limitations. Small-scale topography of the atmosphere was not considered in the WindSim. It also does not provide simple method of including obstacles especially for forests and hedges. It was found that, it would be difficult to run the WindSim models in extremely complex terrains to get the results in desired higher resolutions as no solutions is established yet for the problem [45].

Another research was conducted by Technical University of Denmark (DTU) in which CFD stimulations are used to compare the wind speed profiles with the WAsP for a site located in Green Land. For the sites analyzed, the difference of wind speeds resulted from both models was 10% that is not an acceptable value for wind resource assessment. However, the result shows known WAsP difficulty in predicting fluid separation due to simple computational model used in the software [46].

If we compare CFD and WAsP, CFD user expertise on results is necessary in advance. The model setup can be quite complex and results are much dependent on the user options. Interface and user based results and pre analysis results expectations push CFD aside from bankable wind studies. Across the other side, WAsP is more user friendly or more users can easily obtain the same results.

2.8 Wind Power Policies

There are numbers of policies worldwide for the development of wind power technologies. These include renewable energy generating electricity system including Fixed electricity price system, Tender pricing System, Green electricity price System, Quota system of renewable energy. There are also incentive systems includes Low interest loan policy, price policy, taxes policy and subsidy policy etc. Among all the policies worldwide, policies developed by China are encouraging and successful. Ping Liu et al. suggests to define national development goals to encourage local governments, grid electricity enterprises, power generating enterprises and manufacturing industries to have directions and goals. It is also suggested to introduce economic incentive policies beneficial to each party, protecting local economic profits and announcing management measures for Renewable Energy Funds, increasing openness of fund collection and use of development of equally beneficial measures for the development of renewable energy technologies on fast track [47]. Szarka Joseph, explores the extent to which policy models from countries like Denmark, France and UK led to new understanding of ways to support wind energy technology and integrate economic, environmental, and social capacity for the sustainable development [48]. Baradale. M. J compared various policy incentives of different countries and their role in supporting long-term investment in wind technology. He explained that how US wind industry has followed a volatile boom-bust pattern of investment closely linked to the short term renewal and expiration cycle of the federal production tax credit (PTC), the primary support for wind power generation [49].

2.9 Wind Power Technology in Pakistan

Rapid depletion of fossil fuels diverted the attention of government to initiate a major program of wind speed measurement and installation of large wind farms at locations that have been deemed fit for this purpose. The key factor behind the present revival of renewable energy activity within Pakistan is the establishment of Alternative Energy Development Board (AEDB) by the Government of Pakistan in 2003. AEDB installed wind-measuring instruments in Southern Pakistan at Gharo, which recorded the data for the period of 04 years (May 2002-June 2006) at a minute's frequency to assess the potential of wind power in the area [50].

Almost 70% of the population of Pakistan is living in remote and rural places, which are still not connected to the national grid. At present Pakistan needs to focus on the development of its indigenous energy resources like hydropower, solar and wind. This will help to overcome the energy shortage of the country in general and to provide electricity to the remote communities of Pakistan. More than 1000 km long coastline in south and some places of northern mountainous areas are estimated to potentially generate huge wind power that can be utilized to produce electricity on both small scale and large-scale applications [50].

2.10 Baseline Wind Data Availability in Pakistan

In developing countries like Pakistan the long-term meteorological data is either unavailable or it is incomplete or it is unreliable, thus limiting it's utility. Similarly specialized data collected for the promotion of wind energy production is often of limited value since it is not generated by following international standards (IEC, IEA) and best practice. Thus private investors in such countries are left with the only option to collect their own data by following standards demanded by the lenders and financers. This is not only costly but can also delay the start of the project for several years [53].

The very first efforts to identify possible potential of wind energy for water pumping and aero-generation in Pakistan were in 1980s.

Harijan et al. [51] assessed the per unit cost of electricity generation from 15 MW wind farm at 40 locations in coastal areas of Pakistan using the net present value analysis. It has been estimated that a 15MW wind farm can generate 28-40 GWh and 12-20 GWh electricity per year at different locations in the coastal areas of Sindh and Balochistan provinces. Using the Net Present Value (NPV) analysis, the cost of electricity generation is found to be 4.2UScents/kWh at Jamshoro, while corresponding maximum was 7.4 UScents/kWh at Kadhan Site.

Harijan et al. [52] in other research work describes the penetration of wind market in Pakistan in different policy scenarios by using logistic approach and analogue approach. According to him 40-70% of the total wind energy generation potential of Pakistan could be exploited by the year 2030 under Standard and optimistic scenario.

CHAPTER 3 : UNRELIABILITY AND RELIABILITY OF WIND DATA-FACTORS, ANALYSIS AND COMPARISON

3.1 Unreliability Factors of Wind Data

As discussed earlier in Chapter-1 and Chapter-2, the exceptional wind regime of the coastal areas of Pakistan has attracted many national and international private investors. A major barrier in the realization of the wind power projects is the non-availability of the reliable historical wind data and the available short-term wind data not being as per international standards.

The reason for unreliable, inaccurate or incomplete data could be poor configuration, equipment failure or inadequate data handling processes that can have negative results for the finances of a project. The major factor that affects the efficiency of the wind farm development is the unreliable wind speed data.

Therefore, the author visited unreliable wind masts installed by PMD and the reliable masts installed as per international standards in the south of Pakistan. Author considered the reliable masts as those, which fulfill the international standard stated in IEC-61400-12-1: 2005 which is most significant in describing the optimal installation of wind masts and sensors.

During visits of masts the author compared the wind speed data gathered from both reliable and unreliable wind masts and identified the pros and cons of wind mast installed and quality of data retrieving from those masts. The wind data used for the comparison for both unreliable and reliable wind mast was taken from Alternative Energy Development Board. The Author during his visit analyzed the errors in the installation of mast with respect to specific areas which is presented in this chapter and recommendations are given in Chapter-4 to overcome those shortcomings.

In the first phase, two unreliable masts of Gharo and Nooriabad installed by Government of Pakistan were visited. All these data sources were visited as they have

been collecting data for a long time. In order to use the available time series data at the mentioned location were supposed to help for establishing wind regime in the area.
After the visit, it was observed that the mast have been collecting data for past more than two (02) years but configuration of these mast, equipment calibrations were not up to the mark that can be used for the purpose of project development and lenders confidence. Therefore, author needed to visit the other mast installed in line with international standards. These masts were collecting data for a very small time therefore it was not possible to completely bank on these reliable masts.

Based on the pro and cons of both scenarios, author finally established correlation between two masts and established benchmark regime in the region.

3.2 Meteorological Mast Installed by Government of Pakistan

3.2.1 Gharo Met Mast

The met mast is located in the village located in southeast of Gharo. It is approximately 60 km in the south east of Karachi. The Gharo met mast is of lattice type having side width of 0.3 m. There are two loggers on the mast; one is recording the data from 50m height anemometer whilst the other one is recording the data for 10 m and 30 m anemometers. PMD is using locally manufactured data loggers of East West Infinity, whereas the anemometers are of NRG.

3.2.1.1 Observation/Anomalies found in Gharo Met Mast

The exposure of the mast is good in the predominant direction sectors. There are few obstacles in the surrounding of met mast, for instance a 3 m high building in the North East approximately 50 m from tower and a boundary wall of 1.3 m in the south-southwest direction of mast.

The discrepancies have been found in the installation of sensors and equipments when compared with the international standard for installation of wind mast (IEC-61400-12-1) and are identified here;

a. The boom length is not sufficient to encounter the distortion effects created by both the tower shadow and boom itself.

b. Wind vane installed on the same boom with anemometer at 50 m height as shown in **Figure 3.1**, which is too close to the tower shown in **Figure 3.2** and cause hindrance to the flow of wind and in turn influence the wind direction readings.

c. The Met mast is surrounded by forest in West, small buildings in the North East and a boundary wall in the South direction of mast causing obstacle and wind speed hindrance impact.

Figure 3.1: Top Mounted Boom Anemometer with Vane

Figure 3.2: Gharo Met Station

3.2.2 Nooriabad Met Mast

The 50 m tall mast is located on Karachi –Hyderabad Super Highway near Nooriabad, it is installed on left of Super Highway behind a Police check post, chowki # 9 (Direction: Karachi-Hyderabad) as shown in **Figure 3.3**.

Figure 3.3: Met Mast behind the Police Check Post

Wind speed at Nooriabad mast is recorded through two locally manufactured data loggers of East West Company by Pakistan Meteorological Department, one logger is connected with the anemometers placed at 10 m and 30 m heights whereas the other logger is recording wind data from top mounted boom anemometer placed at 50 m from ground level.

There was only one obstacle; a police check post in the east of mast and rest of the surrounding area was wide open.

3.2.2.1 Observation/Anomalies found in Nooriabad Met Mast

Following errors have been found in installation during the visit of Nooriabad Met mast.

a. It is found that the boom lengths are not according to the international standard. Anemometer installed on the site as shown in **Figure 3.4**, it is close to the one leg of mast and measuring the wind speed under the tower shadow.

Figure 3.4: Anemometer mounted with Wind Vane on 30 m high boom

b. Wind vane is installed with Anemometer on same boom at 30 m height, which will distort the wind speed if the wind blows in the direction of boom. 50 m top mounted boom anemometer is installed in the middle of the boom, this arrangement is recording wind speeds under the distortion made by tower and squared cross sectional boom.

c. Nooriabad mast has been recording wind data at 10m and 30m since April 2002. The mast is equipped with NRG Systems maximum 40 anemometers, Model No 200 P wind vane and East West Infiniti (Pvt.) Ltd. Lynx 2000 data logger, all of which are calibrated locally and not as per IEC standard. In October 2005, a new anemometer was installed at a height of 50m which has recorded wind data until 2007. Panorama of Nooriabad Wind Mast is shown in **Figure 3.5**.

Figure 3.5: Panorama of Nooriabad Met Mast

3.3 Reliable IEC Standard Masts Installed by Private Sector

Approximately three years after the installation of PMD met masts some private investors have installed international IEC standard wind masts in Gharo and Nooriabad areas. One of these IEC standard wind measuring mast [9] each from Gharo region and Nooriabad region installed by private investors is considered for analysis by the author. In this section a brief description of the IEC standard masts are given which highlights the difference between these reliable IEC standard wind mast and unreliable PMD masts. It is important because the data of these two masts is used to compare the results and verify the approach adopted by the government of Pakistan on the recommendations of the author to mitigate "*Wind Risk*" and promote fast track development of wind energy program in Pakistan.

3.3.1 Green Power Met Mast (Reliable Wind Mast)

The proposed wind farm site is located approximately 50 km southeast of Karachi, in the Gharo region.The Wind farm site is flat area at approximately 2m to 5m above sea level. The general terrain of the site is simple. There are no major obstacle on the site. Similar terrain is found in the north, south, and west of the terrain. Towards East, the terrain rises gradually and ground cover changes to become more agricultural, with some small areas of forestry.The author has visited the farm site in December 2006. The surface roughness length of the site and surrounding areas was assessed during the site visit. The roughness was generally low. There were low height bushes with water channels flowing inside the land.

The 60m tall wind mast is of lattice structure and side width of 0.3m as shown in **Figure 3.6**. The mast has been found in good condition and the installation of sensors was made as per International standards.

Figure 3.6: Top Mounted Boom Anemometer Installed on Green Power Mast

3.3.2 Zorlu Energy IEC Standard Reliable Wind Mast

The mast was installed in March 2007 and has started collecting the wind data since then. The mast is lattice structure with triangular cross section having side width of two (02) ft. The installation arrangement at the mast can be seen from the **Figure 3.7** whereas the roughness of the area can be viewed through the panoramic view given in **Figure 3.8.**

Figure 3.7: View of Zorlu Mast

Figure 3.8: Neighborhood of Zorlu Mast

Wind measuring mast is installed as per the wind energy standard (IEC 61400-12).. Wind Speed at Zorlu Mast is recording data through Wilmer's data logger. The sensor arrangement at the mast is given in **Table 3.1** as below:

Table 3-1: Installation arrangement of Sensors at Zorlu Mast

Anemometer(s)	**Wind Vane(s)**	**Temperature**
WS 85-a (85m)	Dir 80 (80m)	Temp 80 (80m)
WS 85-b (85m)	Dir 30 (30m)	Temp 5 (05m)
WS 60 (60m)	-	-
WS 30 (30m)	-	-
WS 10 (10m)	-	-

WS 85-a and WS85-b are the top mounted boom anemometers, these anemometers are clear from the obstruction of the mast.

All sensors were closely analyzed and observed that all sensors are in good working condition. For the selection of one (01) anemometer, WS85-a is used in this report as the anemometer is near to the hub height and the data coverage ratio is better than WS85-b. The mast is installed in the plane area and has no obstruction from any of the direction sectors. Hence, the wind speeds at the mast are not disturbed by any obstacle.

The mast is equipped with Thies First class anemometers, Wilmer wind vane, and Wilmer's data logger. The Anemometers are calibrated through a Measnet accredited wind tunnel by Deutsche Wind Guard.

3.4 Wind Data Analysis

After site visit and collection of site data, data analysis is carried out. For the data analysis, raw data from the data logger is extracted. After data extraction from logger, data is analyzed for parameters. Details of these parameters and methodology to calculate them is given as below:

a. **Data Acquisition Ratio:** It is ratio of actual number of records available to the ideal number of records. As per the wind measurement campaigns, data is collected for every ten (10) minutes interval. There may be chances that fault data is logged in logger. These fault values may be due to lightening strike, equipment failure. Therefore, ideal numbers of records are decreased as compared to the actual records received. Therefore, acquisition ratio is decreased. Since this is ratio and always equal to one (01) or less than one (01), therefore it is taken in percentage (%).

b. **Wind Shear:** Wind shear refers to a change in wind speed or direction with height in the atmosphere. Shear is one of the reasons that can cause a rapid change in lift, and thus affecting the drag. In this way, turbine performance is strongly influenced due to difference of wind shear. Wind shear is important for the formation of tornadoes and hail. Generally, turbine manufactures are offering power curve of turbines that are qualified having upper value of wind shear as 0.2. If a site, wind shear is higher, than it is required to consult with turbine manufacturer to offer site based power curve. Some amount of wind shear is always present in the atmosphere, but particularly strong wind shear.

c. **Monthly average, Diurnal Averages and Monthly Averages:** For the data analysis and impact with reference to cycle over a day, month and year; vaious plots are helpful. A Diurnal plot is used to analyze the behavior of wind over a complete day. Monthly plots are used to find out the cycles over year with resolution of results with 12 values and annual plots are used to find out trends over each year. Such plots have been used for the wind speed, wind shear.

3.5 Wind Data Analysis of Nooriabad Met Mast (Reliable Mast)

3.5.1 Mast Details

The wind analysis is conducted using wind data for the period of January 2003 to December 2007. The wind data for the analysis is taken from the Alternative Energy Development Board (AEDB) Government of Pakistan. Wind data logged for 2007 has many inconsistencies and anomalies, which are not supposed to be present in the data.

It happened because the logger and the sensors started malfunction. The location of the Nooriabad wind mast and the items measured are shown in **Table 3.2.**

Table.3-2: Specification of Nooriabad Wind Mast

Latitude	25^{o} 10.906' N
Longitude	67^{o} 48.719' E
Observation	Wind speed, wind direction, temperature,
Observation height	10m: wind speed 30m: wind speed, wind direction 50m: wind speed
Observation period	January 3003 - December 2007

The wind data gathered from the Nooriabad met mast for the period of five years i.e. from January 2003 to December 2007 has been analyzed but the production of energy yield is made on data covering January 2003 - December 2006 period.

3.5.2 Data Acquisition Ratio

The wind data acquisition ratio of Nooriabad met mast is shown as 90.59% in **Table 3.3.** It is ratio of valid actual number of records available to the ideal number of records. As per the wind measurement campaigns, data is collected for every ten (10) minutes interval. There may be chances that fault data is logged in logger. These fault values may be due to lightning strike, equipment failure. Therefore, ideal number of records are decreased as compared to the actual records received. Therefore, acquisition ratio is decreased. Since this is ratio and always equal to one (01) or less than one (01). This value is presented in percentage (%).

In below table, data acquisition ratio is calculated for each month during year 2003 to 2007. For the annual estimation of mean wind speed, all wind speeds are annually averaged in the same table. In the last of table, an average is calculated from year 2003 to 2007. From all values, it shows that data acquisition ration is generally high (>75%) giving confidence that equipment has been working in good condition and results developed from the data will be representative of the site.

The average monthly and annual wind speed acquisition ratio of Nooriabad met mast is shown as 90.59% in **Table 3.3**.

Table 3-3: Wind Speed Acquisition Ratio of Nooriabad Met Mast @ 30m height

Month	Data Acquisition Ratio (%) (2003)	Data Acquisition Ratio (%) (2004)	Data Acquisition Ratio (%) (2005)	Data Acquisition Ratio (%) (2006)	Data Acquisition Ratio (%) (2007)
January	100%	99.93	99.96	99.94	94.95
February	99.92%	99.95	99.96	99.94	98.62
March	99.94%	87.93	99.95	99.94	99.94
April	99.94%	99.92	99.95	99.95	99.94
May	99.60%	99.93	99.94	97.97	99.93
June	99.24%	98.75	96.73	99.96	9.06
July	99.58%	99.82	99.96	99.92	36.2
August	99.54%	99.95	99.94	92.73	2.00
September	98.78%	99.92	99.79	84.60	39.5
October	99.95%	99.81	99.96	99.96	43.39
November	99.95%	99.96	99.94	99.95	Missing Data
December	99.97%	99.95	99.96	34.29	Missing Data
Annual wind speed acquisition ratio – 2003				99.70%	
Annual wind speed acquisition ratio – 2004				98.82%	
Annual wind speed acquisition ratio – 2005				99.67%	
Annual wind speed acquisition ratio – 2006				92.43%	
Annual wind speed acquisition ratio (2007)				62.35%	
Average wind speed acquisition ratio (2003-2007)				**90.59%**	

3.5.3 Average Wind Speed

After analyzing the data acquisition ratio and getting the confidence on the acquisition ratio, average wind speeds are calculated. The wind data recoded at 30 m height from Nooriabad met mast during the period of five years, i.e. Jan 2003 to Dec. 2007, has been analyzed to determine the monthly mean wind speeds. The monthly mean wind speeds and annual monthly mean wind speeds at Nooriabad Met mast for the duration of January 2003 to December 2007 at 30 m height is shown in **Table 3.4.** The table shows that the wind speeds are higher in the months of summer from April to September. The lower wind speeds are recorded in the months of November and December.

Table 3-4: Monthly Mean and Annual Mean Wind Speeds at Nooriabad (2003 – 2007) at 30 m Height

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MWS 2003	4.260	4.648	4.539	5.809	8.108	9.679	6.630	7.677	7.506	3.070	3.852	3.448
MWS 2004	4.081	3.988	4.235	7.237	8.146	10.759	10.675	11.041	6.969	4.385	3.677	4.610
MWS 2005	4.298	4.118	4.976	5.590	7.257	7.809	9.637	8.343	6.367	4.373	3.179	3.833
MWS 2006	4.342	4.919	5.172	6.324	9.435	7.812	8.033	6.018	4.335	4.553	3.436	4.498
MWS 2007	4.408	4.586	4.290	5.044	6.576	11.268	6.061	4.527	5.589	3.612	-	-
Annual Monthly Mean Wind Speeds (2003-2007)	4.28	4.45	4.64	6.00	7.90	9.47	8.21	7.52	6.15	4.00	3.54	4.10
Annual Mean Wind Speed (2003-2007)	**5.85**											

3.5.4 Diurnal Variations in Wind Speed

Wind speeds vary during the whole day. Major reason of change in wind speed is thermal transitions causing pressure equilibrium disturbed. It is the reason that in the daytime, surface temperature increases in the areas of Sindh and high winds are observed at the surface. At the same time, wind transitions during a day are different for different heights. For example, surface winds can increase whereas winds at high altitude may reduce in daytime. To analyze, transitions of winds and its derived parameters during a day, Diurnal analysis is compulsory.

In **Figure 3.9** given below**,** show the seasonal Diurnal variation of wind speed are analyzed, for the wind data recoded during the period of Jan 2003 to December 2007, at 30 m height. From below figure, it can be observed that wind speed is increased during the day hours in June whereas it is decreasing in November during daytime. It also shows that turbine should be selected for the region that can perform at its rated power during high temperatures.

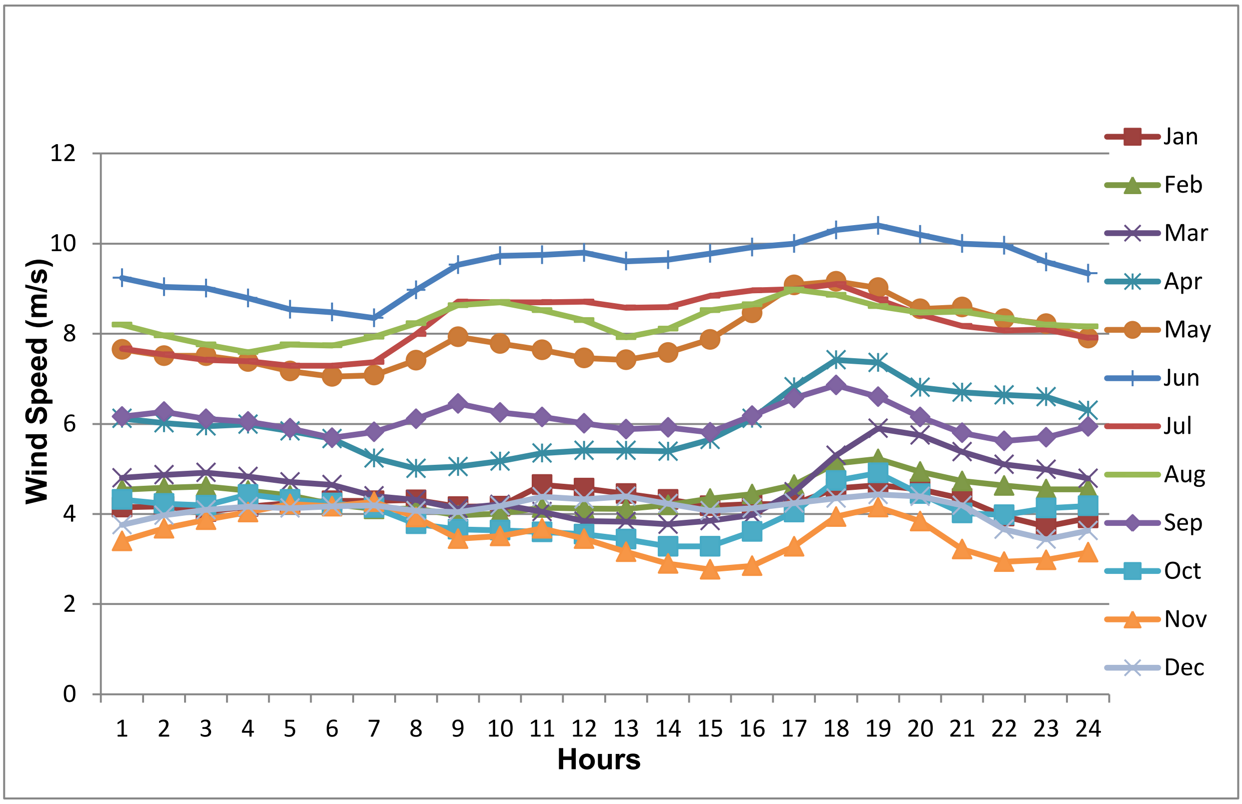


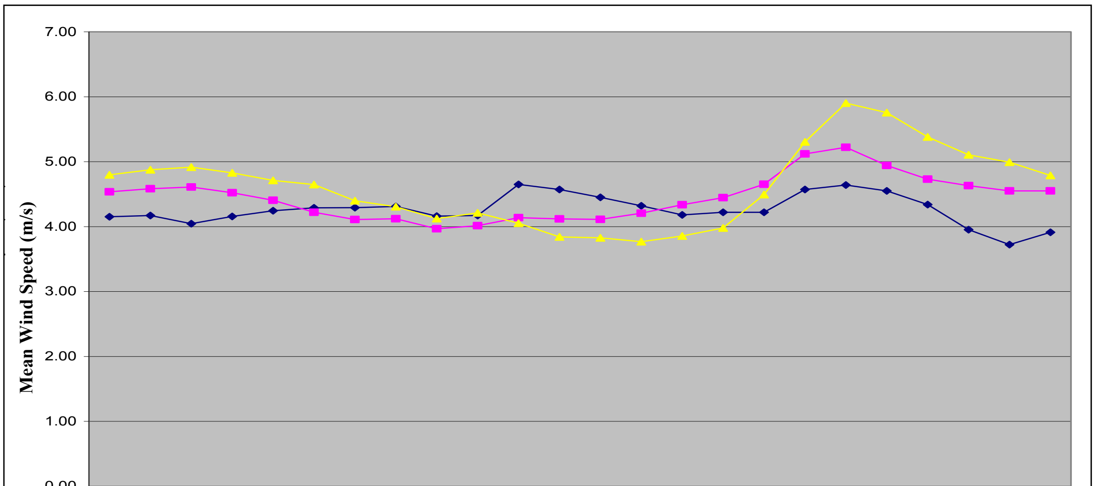
Figure 3.9: Diurnal Wind Speed Variation (January, 2003-December, 2007) at 30 m height

3.5.5 Wind Shear

Wind shear refers to a change in wind speed or direction with height in the atmosphere. Shear is one of the reasons that can cause a rapid change in lift, and thus affecting the drag. In this way, turbine performance is strongly influenced due to difference of wind shear. Wind shear is important for the formation of tornadoes and hail. Generally, turbine manufactures are offering power curve of turbines that are qualified having upper value of wind shear as 0.2. if a site wind shear is higher, than it is required to consult with turbine manufacturer to offer site based power curve.

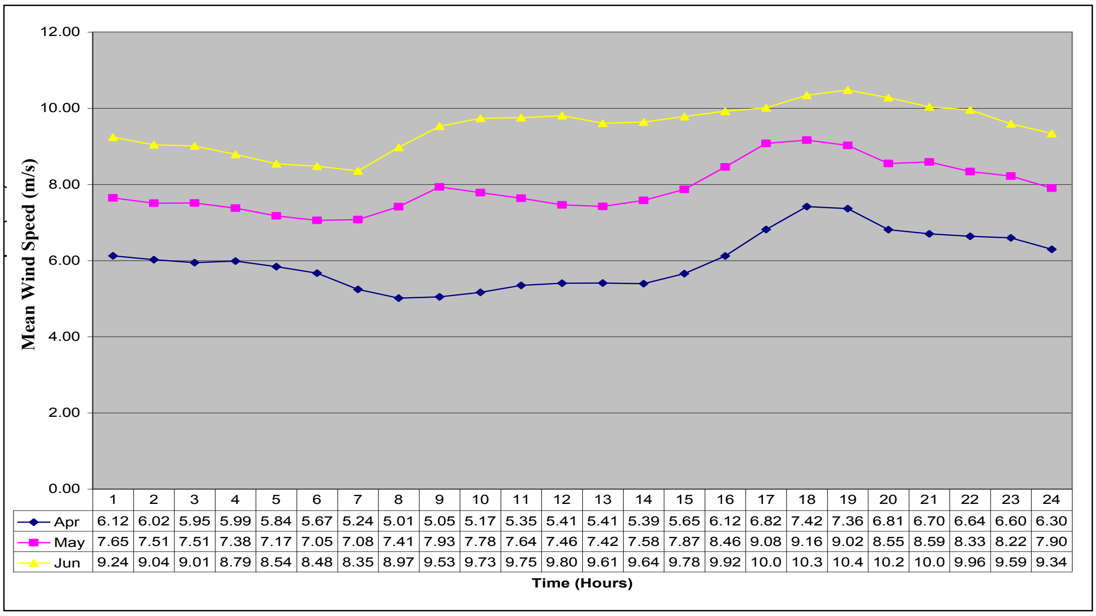
Wind shear has been calculated for Nooriabad met mast during measurement period at the height of 30 m. The same calculated wind shear is used to extrapolate wind speed at different heights using the 'Power Law'.

Figure 3.10, Figure 3.11, Figure 3.12 & **Figure 3.13** show the seasonal Diurnal variation of wind speed, for the wind data recoded during the period of Jan 2003 to December 2007, at 30 m height.



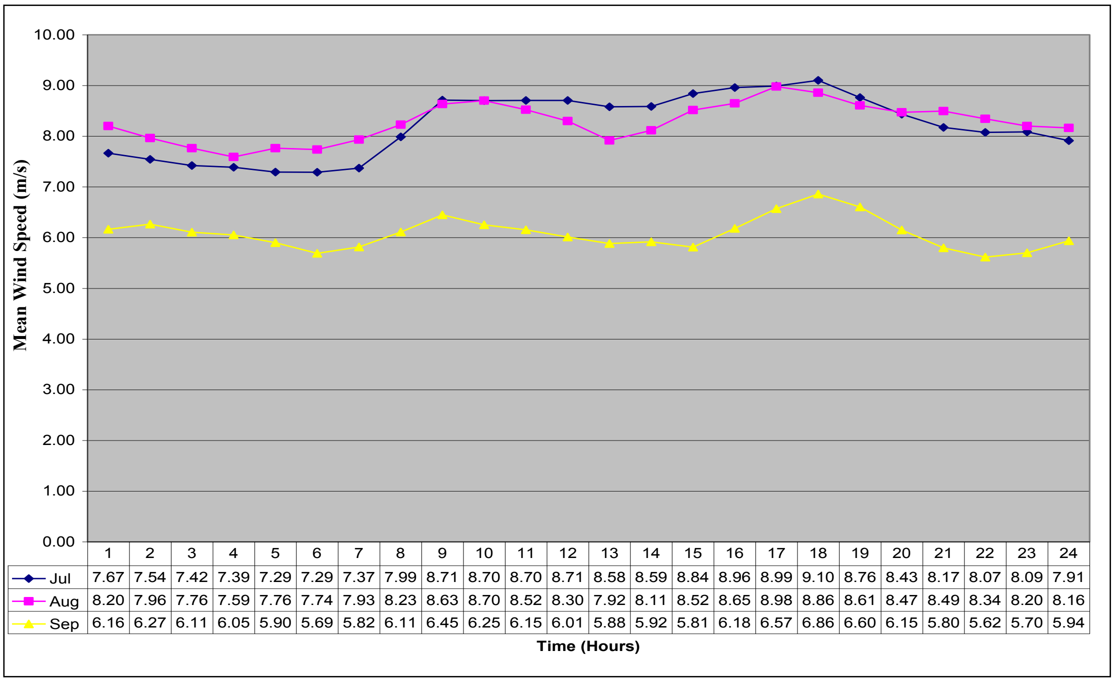
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	4.15	4.17	4.05	4.16	4.24	4.29	4.29	4.31	4.16	4.17	4.65	4.57	4.45	4.32	4.18	4.22	4.22	4.57	4.64	4.55	4.34	3.95	3.72	3.91
Feb	4.54	4.58	4.61	4.52	4.41	4.22	4.11	4.12	3.97	4.01	4.14	4.12	4.11	4.20	4.34	4.44	4.65	5.12	5.22	4.94	4.73	4.63	4.55	4.55
Mar	4.80	4.87	4.92	4.83	4.71	4.65	4.40	4.31	4.12	4.21	4.05	3.84	3.83	3.77	3.85	3.98	4.49	5.30	5.90	5.75	5.38	5.10	4.99	4.79

Figure 3.10: Diurnal Wind Speed Variation (Jan-Mar)(30m)



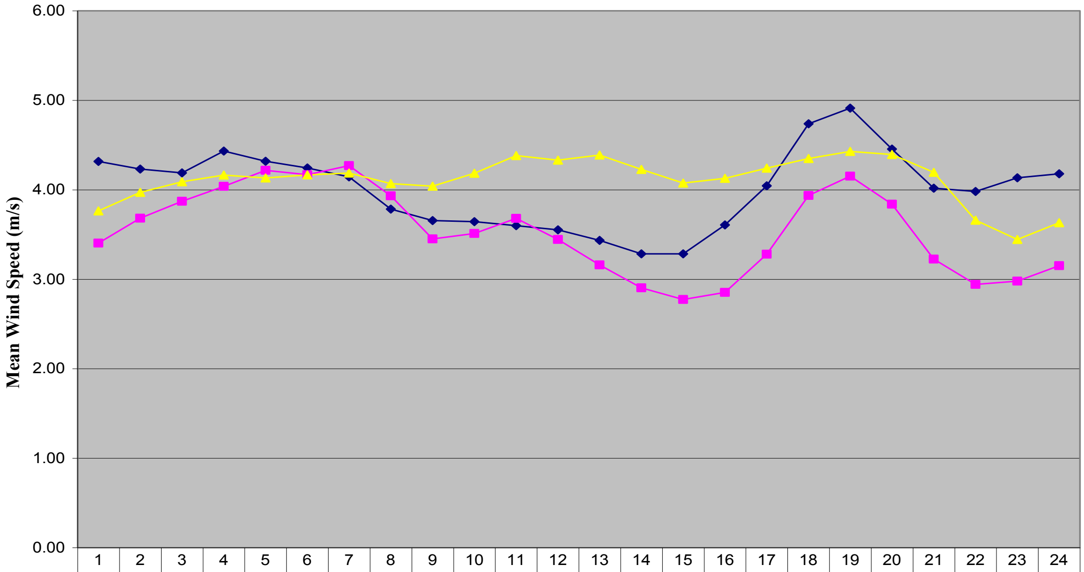
Time (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Apr	6.12	6.02	5.95	5.99	5.84	5.67	5.24	5.01	5.05	5.17	5.35	5.41	5.41	5.39	5.65	6.12	6.82	7.42	7.36	6.81	6.70	6.64	6.60	6.30
May	7.65	7.51	7.51	7.38	7.17	7.05	7.08	7.41	7.93	7.78	7.64	7.46	7.42	7.58	7.87	8.46	9.08	9.16	9.02	8.55	8.59	8.33	8.22	7.90
Jun	9.24	9.04	9.01	8.79	8.54	8.48	8.35	8.97	9.53	9.73	9.75	9.80	9.61	9.64	9.78	9.92	10.0	10.3	10.4	10.2	10.0	9.96	9.59	9.34

Figure 3.11: Diurnal Wind Speed Variation (April-June)(30m)



Time (Hours)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jul	7.67	7.54	7.42	7.39	7.29	7.29	7.37	7.99	8.71	8.70	8.70	8.71	8.58	8.59	8.84	8.96	8.99	9.10	8.76	8.43	8.17	8.07	8.09	7.91
Aug	8.20	7.96	7.76	7.59	7.76	7.74	7.93	8.23	8.63	8.70	8.52	8.30	7.92	8.11	8.52	8.65	8.98	8.86	8.61	8.47	8.49	8.34	8.20	8.16
Sep	6.16	6.27	6.11	6.05	5.90	5.69	5.82	6.11	6.45	6.25	6.15	6.01	5.88	5.92	5.81	6.18	6.57	6.86	6.60	6.15	5.80	5.62	5.70	5.94

Figure 3.12: Diurnal Wind Speed Variation (July-Sep)(30m)

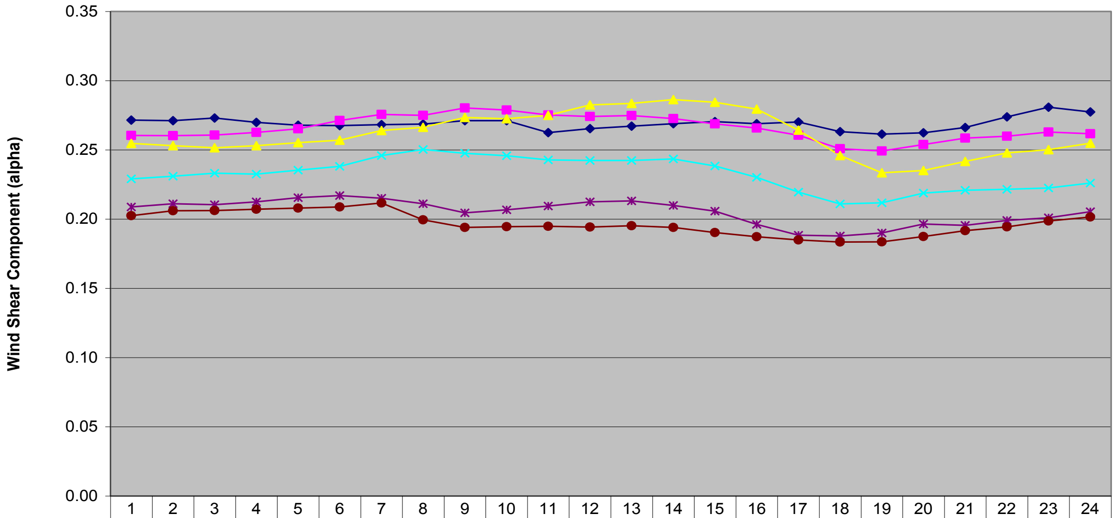


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Oct	4.32	4.23	4.19	4.43	4.32	4.24	4.14	3.78	3.66	3.64	3.60	3.55	3.44	3.28	3.28	3.61	4.04	4.74	4.91	4.45	4.02	3.98	4.13	4.18
Nov	3.40	3.68	3.87	4.04	4.22	4.17	4.27	3.93	3.45	3.51	3.68	3.45	3.16	2.90	2.77	2.85	3.28	3.94	4.15	3.84	3.22	2.94	2.98	3.15
Dec	3.76	3.97	4.09	4.16	4.13	4.17	4.19	4.07	4.04	4.18	4.38	4.33	4.39	4.23	4.07	4.13	4.24	4.35	4.43	4.39	4.19	3.66	3.44	3.63

Time (Hours)

Figure 3.13: Diurnal Wind Speed Variation (Oct-Dec)(30m)

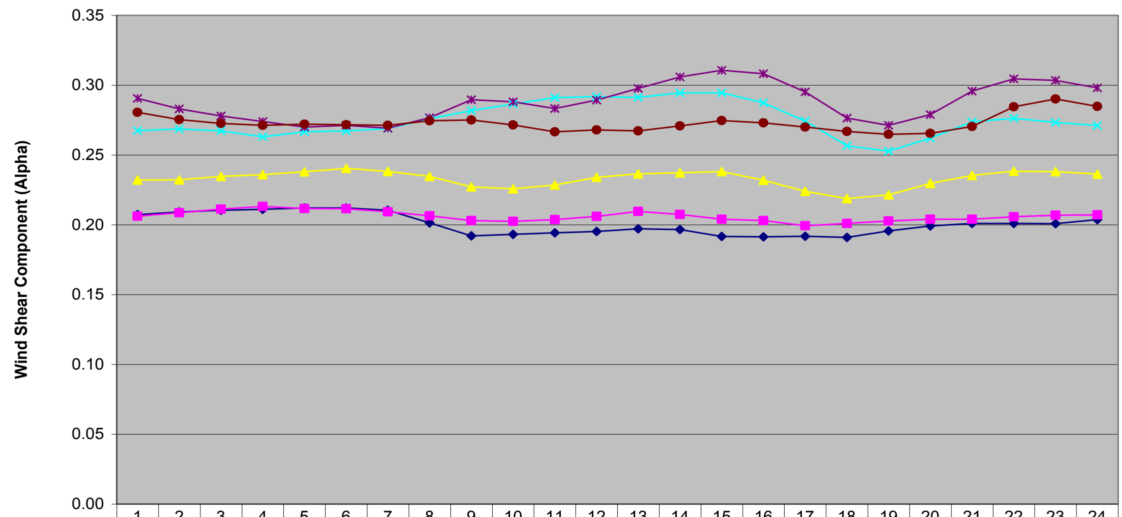
The diurnal wind shear exponents at 30 m height for the months of January to December are presented in **Figure 3.14** and **Figure 3.15**.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.26	0.26	0.27	0.27	0.28	0.28
Feb	0.26	0.26	0.26	0.26	0.27	0.27	0.28	0.27	0.28	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.26	0.25	0.25	0.25	0.26	0.26	0.26	0.26
Mar	0.25	0.25	0.25	0.25	0.26	0.26	0.26	0.27	0.27	0.27	0.27	0.28	0.28	0.29	0.28	0.28	0.26	0.25	0.23	0.24	0.24	0.25	0.25	0.25
Apr	0.23	0.23	0.23	0.23	0.24	0.24	0.25	0.25	0.25	0.25	0.24	0.24	0.24	0.24	0.24	0.23	0.22	0.21	0.21	0.22	0.22	0.22	0.22	0.23
May	0.21	0.21	0.21	0.21	0.22	0.22	0.22	0.21	0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.21
Jun	0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.19	0.19	0.19	0.19	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.19	0.19	0.19	0.20	0.20

Time (Hours)

Figure 3.14: Diurnal Wind Shear Exponents (Jan-Jun)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jul	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.19	0.19	0.19	0.20	0.20	0.20	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.20	0.20
Aug	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.21	0.21
Sep	0.23	0.23	0.23	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.24	0.24	0.24	0.23	0.22	0.22	0.22	0.23	0.24	0.24	0.24	0.24
Oct	0.27	0.27	0.27	0.26	0.27	0.27	0.27	0.28	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.27	0.26	0.25	0.26	0.27	0.28	0.27	0.27
Nov	0.29	0.28	0.28	0.27	0.27	0.27	0.27	0.28	0.29	0.29	0.28	0.29	0.30	0.31	0.31	0.31	0.30	0.28	0.27	0.28	0.30	0.30	0.30	0.30
Dec	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.26	0.27	0.27	0.28	0.29	0.28

Time (Hours)

Figure 3.15: Diurnal Wind Shear Exponents (Jul-Dec)

The monthly mean wind speeds at Nooriabad mast at 30m has been extrapolated at different heights using the Power Law from equation (A) given as below [55]:

The power law is stated as;

$$U_z = u_{ref}\left(\frac{z}{z_{ref}}\right)^{\propto} \qquad \text{(A)}$$

Where;

- U_Z is mean wind speed at height z above ground level
- u_{ref} is wind speed at refrence height
- z_{ref} is reference height
- z is height above ground level
- α is power law exponent

To implement the power law, power law exponent is calculated by correlation of power law exponent as function of reference velocity and height given as below [55]:

$$\alpha = \frac{0.37 - 0.088 \times \ln(Uz)}{1 - 0.088 \times \ln\left(\frac{Z}{10}\right)} \qquad \text{(B)}$$

Using above function given in equation (B), average power law exponent (α) is calculated as 0.24 whereas monthly range from 0.19 to 0.28 with standard deviation of 0.03.

Power law exponent calculated above is used to extrapolate wind speed from 30 m height to 50, 67 and 80 m heights using power law using equation A. results are given in **Table 3.5**.

Table 3-5: Monthly Mean Wind Speeds on Nooriabad Mast

				Monthly Mean Wind Speed (m/sec)				
Month	**Uref**	**Zref**	**Alpha**	**Velocity (30)**	**Velocity (50)**	**Velocity (60)**	**Velocity (67)**	**Velocity (80)**
Jan	4.3	30	0.268	4.3	4.9	5.2	5.3	5.6
Feb	4.5	30	0.263	4.5	5.1	5.4	5.6	5.8
Mar	4.6	30	0.261	4.6	5.3	5.5	5.7	5.9
Apr	6	30	0.235	6	6.8	7.1	7.2	7.6
May	7.9	30	0.208	7.9	8.8	9.1	9.3	9.7
Jun	9.5	30	0.190	9.5	10.5	10.8	11.1	11.4
Jul	8.2	30	0.205	8.2	9.1	9.4	9.7	10.0
Aug	7.5	30	0.213	7.5	8.4	8.7	8.9	9.2
Sep	6.2	30	0.232	6.2	7.0	7.3	7.5	7.8
Oct	4	30	0.275	4	4.6	4.8	5.0	5.2
Nov	3.5	30	0.288	3.5	4.1	4.3	4.4	4.6
Dec	4.1	30	0.272	4.1	4.7	5.0	5.1	5.4
Average	5.9	30	0.237	5.9	6.6	6.9	7.1	7.4

3.5.6 Wind Rose

A wind rose is developed to show direction of wind. A wind rose is presented on radar plots showing the frequency of wind from particular direction. The wind rose developed on the pattern at Nooriabad shows that most of the time the wind direction is from southwest direction to northeast direction as shown in **Figure 3.16.**

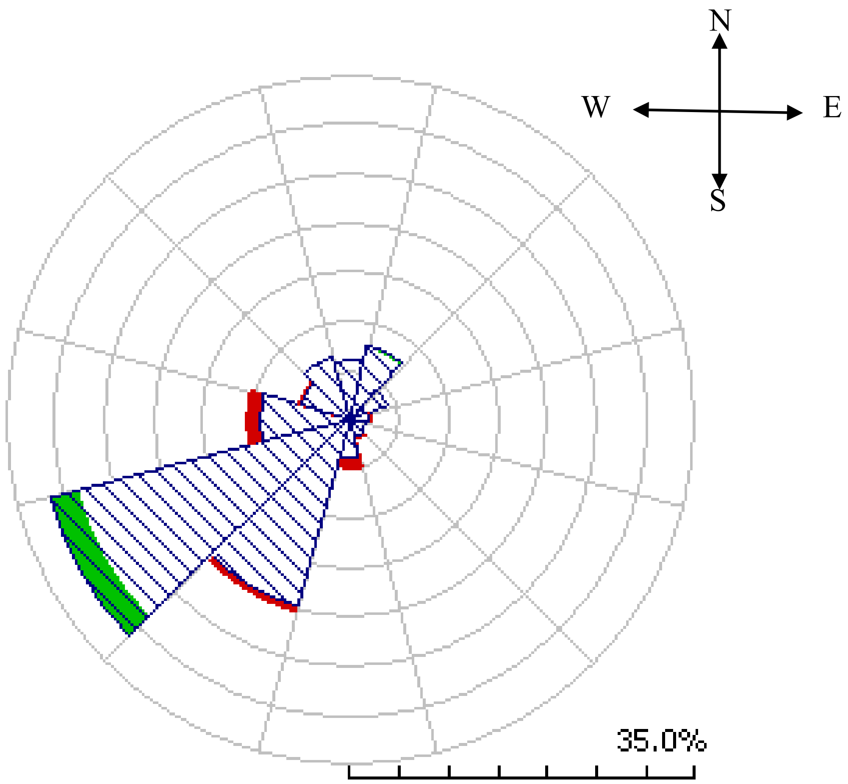


Figure 3.16: Wind rose at Nooriabad Met Station

3.6 Wind Data Analysis of Zorlu Met Mast (Reliable Mast)

3.6.1 Mast Information

Zorlu Mast is recording the data since March 2007. The company has provided 33 months of wind data for the analysis in this study. The data was thoroughly inspected and checked for different anomalies.

The wind analysis has been conducted using wind data from March 2007 to November 2009. The location of the Zorlu Mast and the items measured are shown in **Table 3.6**.

Table 3-6: Specification of Zorlu Mast

Latitude	25^o 03' 58.50'' N
Longitude	67^o 58' 03.10'' E
Observation	Wind speed, wind direction, temperature
Observation height	85m: wind speed (2 anemometers) 60m: wind speed (1 anemometer) 30m: wind speed (1 anemometer) 10m: wind speed (1 anemometer) 80m and 30m wind direction 80m and 5m Temperature
Data used for the Analysis	March 2007 to November 2009

3.6.2 Data Acquisition Ratio

The annual and monthly wind data acquisition ratio from year 2007-2009 is of Zorlu Mast is 98.21% as presented in **Table 3.7**.

Table 3-7: Wind Speed acquisition ratio of Zorlu Mast (Wind Speed @ 85 m))

Month	Data Acquisition Ratio (2007) (%)	Data Acquisition Ratio (2008) (%)	Data Acquisition Ratio (2009) (%)
January	-	100	100
February	-	100	100
March	99.3%	100	100
April	99.9%	100	100
May	95%	100	100
June	96.6%	100	100
July	96.6%	100	100
August	*acquisition ratio is less than 80% therefore this month is not considered	100	100
September	100%	100	100
October	100%	100	100
November	93%	100	100
December	100%	100	100
Annual wind speed acquisition ratio – 2007			96. 12%
Annual wind speed acquisition ratio – 2008			100%
Annual wind speed acquisition ratio – 2009			100%
Average wind speed acquisition ratio (2007-2009)			98.21%

3.6.3 Average Wind Speed

The wind data recorded at different heights from Zorlu Mast during the period of 33 months, i.e. March 2007 to Nov 2009, has been analyzed to determine the monthly mean wind speeds. The results are shown in **Figure 3.17**, **Table 3.8** and **Table 3.9**.

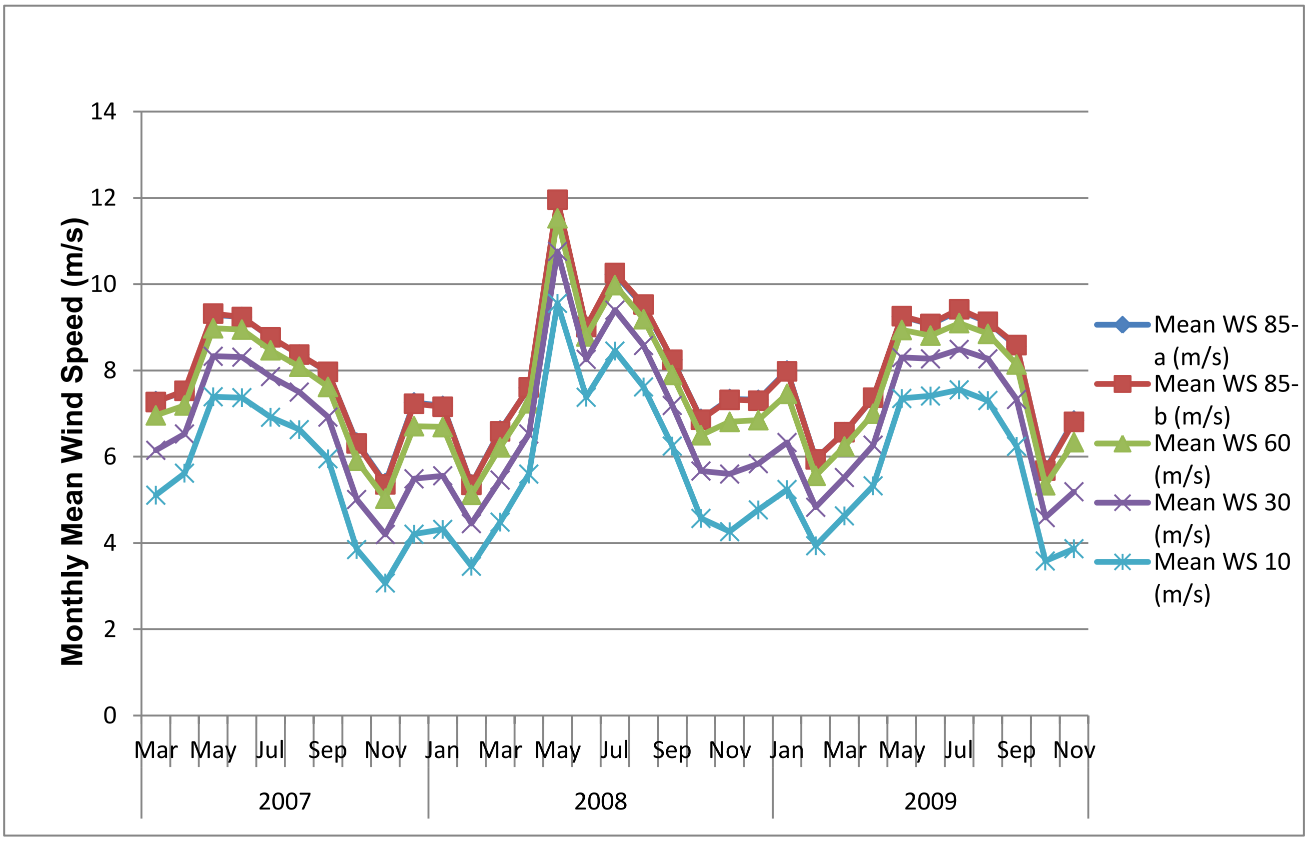


Figure 3.17: Monthly Mean Wind Speeds at Zorlu Mast

Table 3-8: Monthly Mean Wind Speeds at Zorlu Mast March 2007 – Nov 2009

Year	Month	Mean WS 85-a	Mean WS 85-b	Mean WS 60	Mean WS 30	Mean WS 10
		(m/s)	(m/s)	(m/s)	(m/s)	(m/s)
2007	Mar	7.29	7.27	6.96	6.15	5.110
2007	Apr	7.51	7.53	7.19	6.53	5.620
2007	May	9.29	9.32	8.98	8.33	7.392
2007	Jun	9.24	9.24	8.95	8.31	7.371
2007	Jul	8.76	8.77	8.47	7.86	6.916
2007	Aug	8.37	8.37	8.09	7.50	6.630
2007	Sep	7.96	7.97	7.62	6.92	5.954

2007	Oct	6.33	6.31	5.91	5.01	3.849
2007	Nov	5.39	5.36	5.03	4.20	3.074
2007	Dec	7.26	7.23	6.71	5.49	4.205
2008	Jan	7.18	7.16	6.69	5.56	4.317
2008	Feb	5.36	5.35	5.12	4.45	3.462
2008	Mar	6.61	6.59	6.22	5.46	4.485
2008	Apr	7.60	7.61	7.24	6.53	5.599
2008	May	11.90	11.96	11.53	10.76	9.557
2008	Jun	9.01	9.01	8.79	8.26	7.380
2008	Jul	10.23	10.26	9.98	9.40	8.451
2008	Aug	9.49	9.53	9.19	8.58	7.619
2008	Sep	8.25	8.25	7.90	7.19	6.248
2008	Oct	6.88	6.86	6.50	5.67	4.571
2008	Nov	7.34	7.32	6.81	5.60	4.264
2008	Dec	7.32	7.30	6.85	5.84	4.769
2009	Jan	8.00	7.98	7.46	6.33	5.241
2009	Feb	5.95	5.94	5.56	4.83	3.938
2009	Mar	6.57	6.57	6.24	5.52	4.630
2009	Apr	7.36	7.37	7.00	6.27	5.327
2009	May	9.25	9.26	8.94	8.30	7.352
2009	Jun	9.07	9.08	8.81	8.27	7.409
2009	Jul	9.39	9.42	9.10	8.49	7.553
2009	Aug	9.12	9.13	8.85	8.27	7.305
2009	Sep	8.56	8.59	8.14	7.33	6.242
2009	Oct	5.70	5.68	5.34	4.59	3.584
2009	Nov	6.84	6.81	6.34	5.19	3.869
Average Wind Speed		7.89	7.89	7.53	6.76	5.74

Table 3-9: Monthly Mean Wind Speeds at Zorlu Mast (85m height)

Month	Monthly Mean Wind Speed (m/s)
January	7.59
February	5.66
March	6.82
April	7.49
May	10.15
June	9.11
July	9.46
August	8.99
September	8.26
October	6.30
November	6.52
December	7.29
Annual Mean wind speed	7.80

3.6.4 Monthly Diurnal Average Wind Speed

In order to analyze the wind speed separation during one complete year, dinunral plots has been calculated. These Diurnal graphs are developed for each month. Al these plots are summarized with annual measurements.

From each month, diurnal average wind speeds are calculated. Monthly averages are computed in **Figure 3.18** to **Figure 3.28.** From graphs (Monthly), it is observed that wind separation is relatively high at lower end of the turbine during November to February. Author concludes this separation is due to thermal separation at lower and high installed sensors. However flow is low turbulent during the remaining months of year.

From graphs, it can be observed that wind speed increases during evening hours during March to April. Whereas wind is relatively same during May to July during complete day.

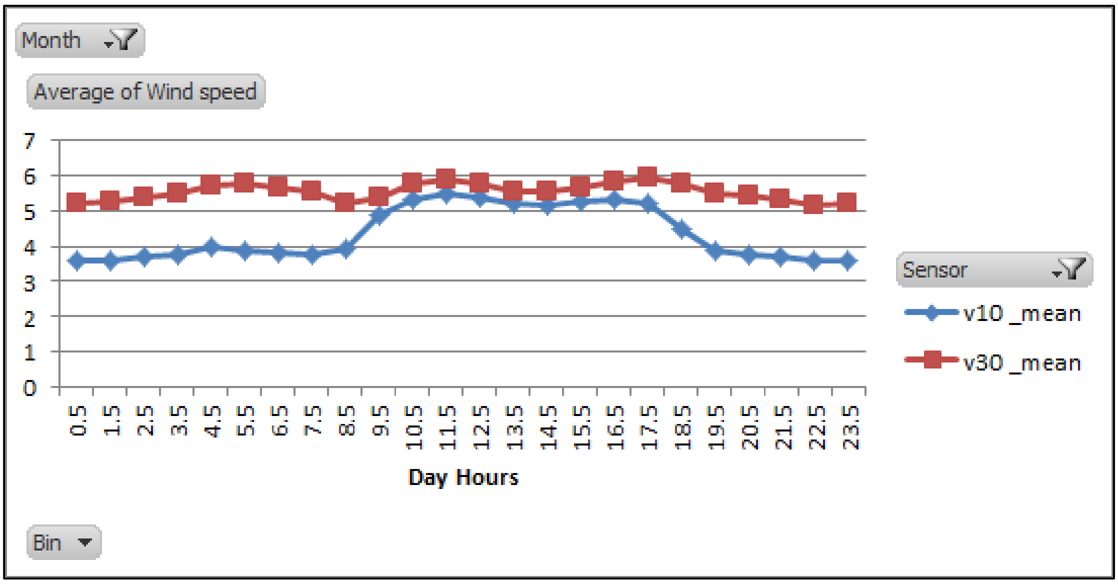


Figure 3.18: Diurnal Wind Speed Variation at Zorlu Mast (January)

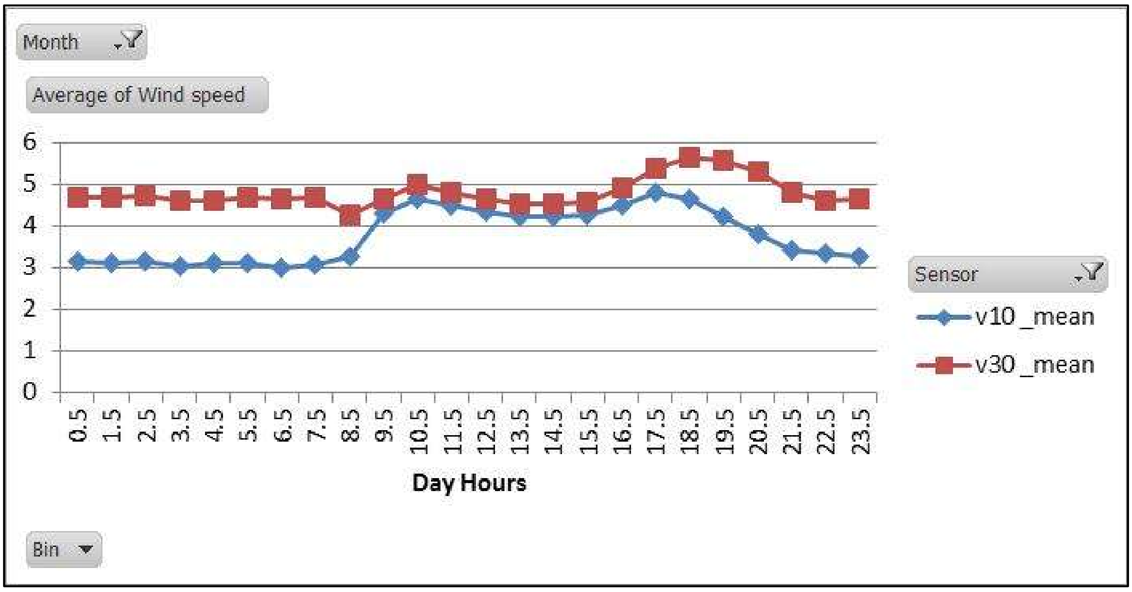


Figure 3.19: Diurnal Wind Speed Variation at Zorlu Mast (February)

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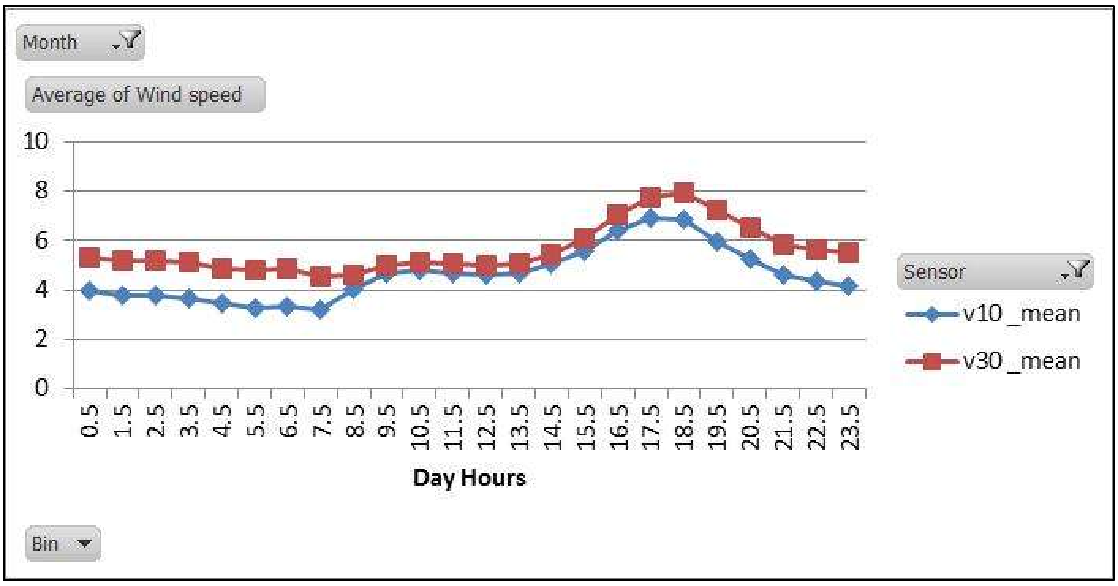


Figure 3.20: Diurnal Wind Speed Variation at Zorlu Mast (March)

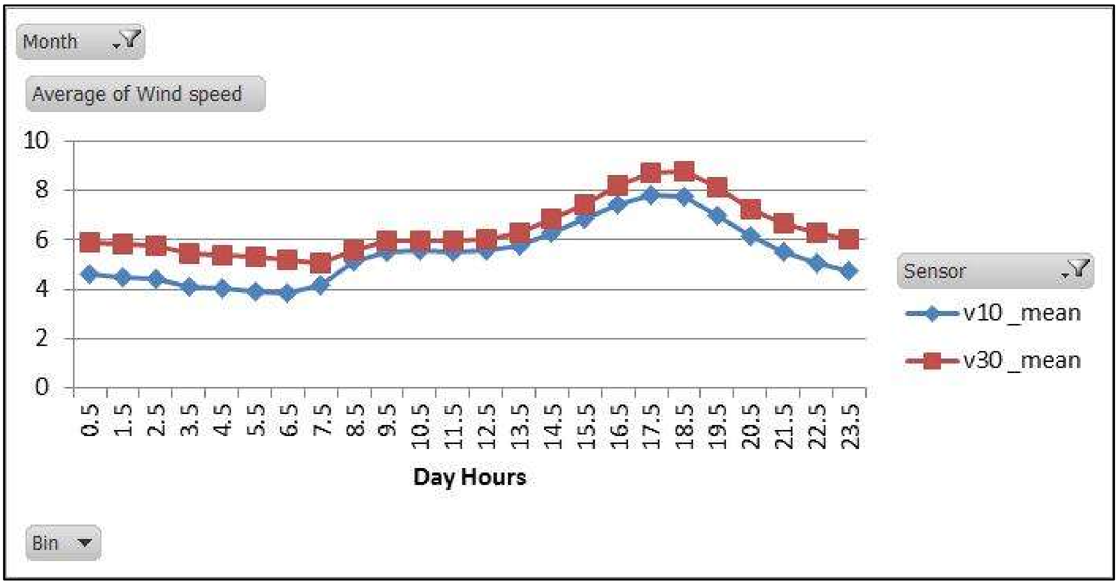


Figure 3.21: Diurnal Wind Speed Variation at Zorlu Mast (April)

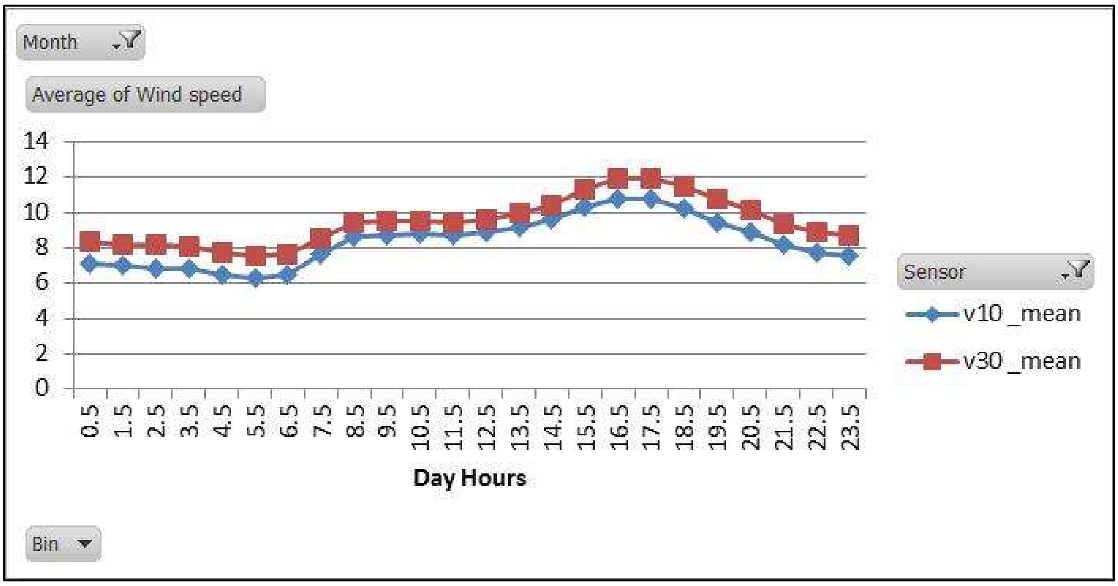


Figure 3.22: Diurnal Wind Speed Variation at Zorlu Mast (May)

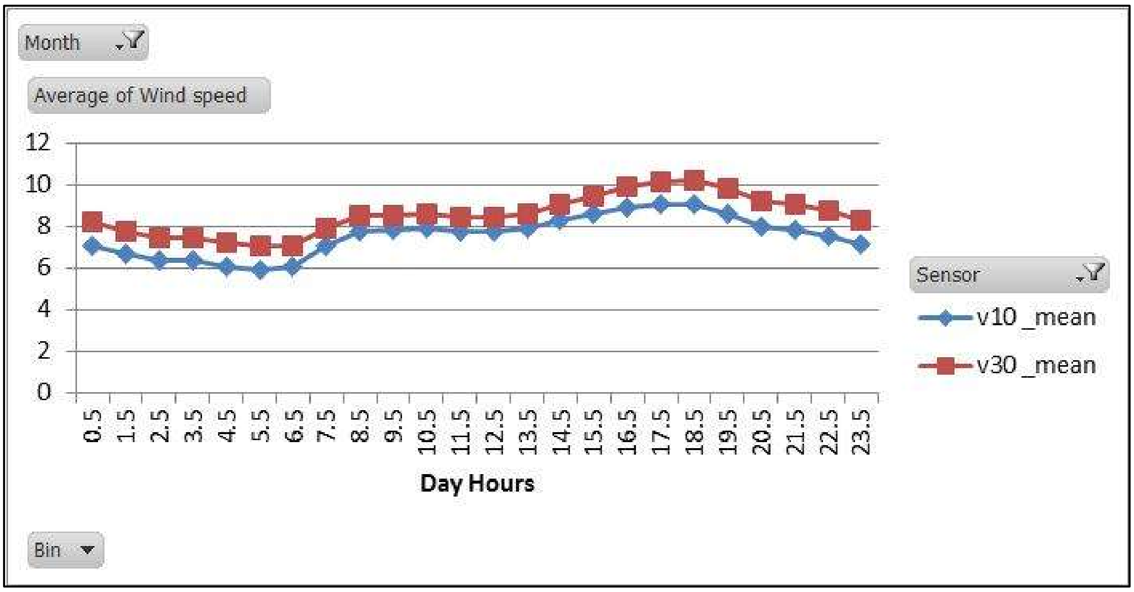


Figure 3.23: Diurnal Wind Speed Variation at Zorlu Mast (June)

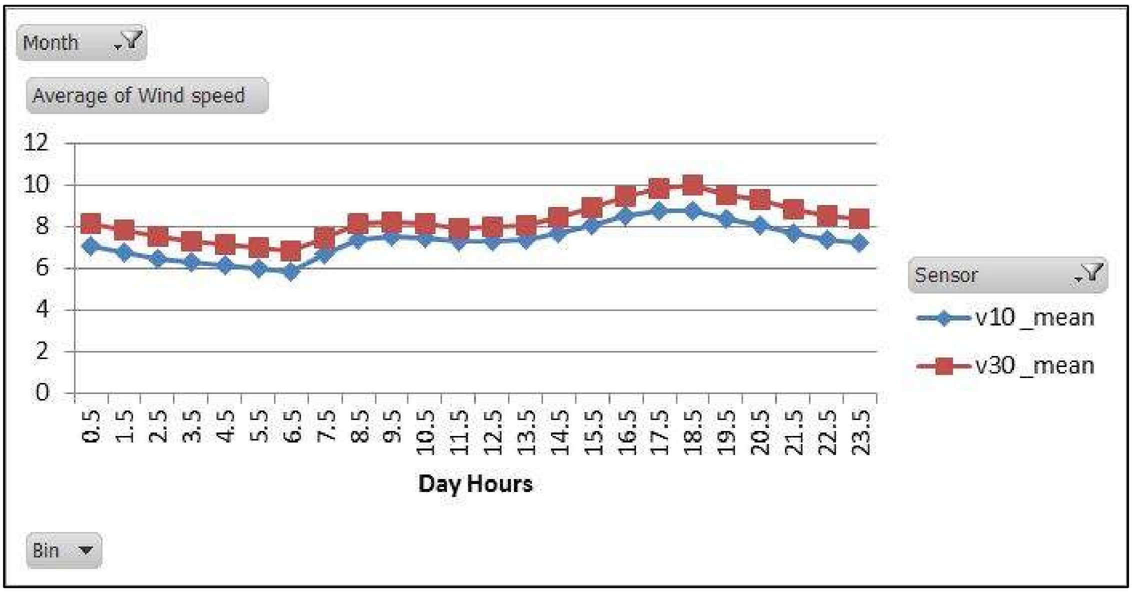


Figure 3.24: Diurnal Wind Speed Variation at Zorlu Mast (July)

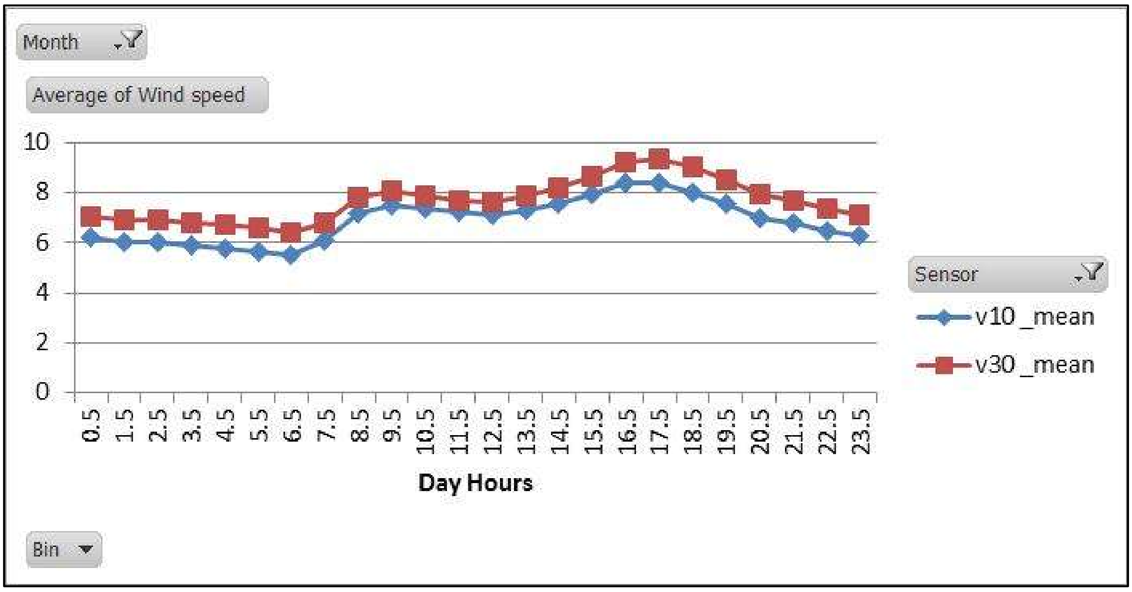


Figure 3.25: Diurnal Wind Speed Variation at Zorlu Mast (August)

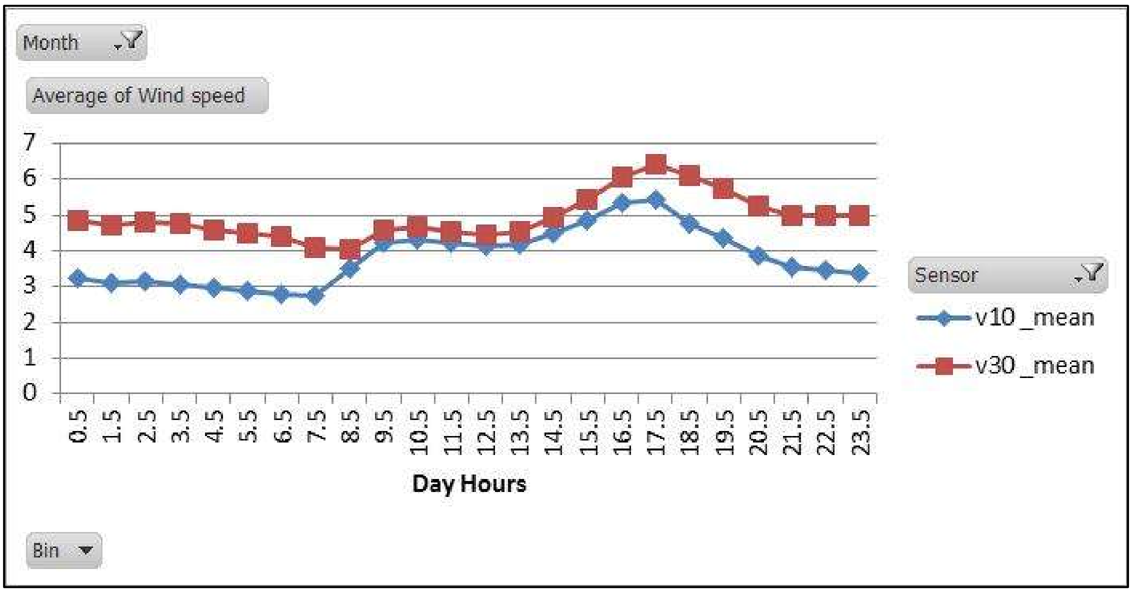


Figure 3.26: Diurnal Wind Speed Variation at Zorlu Mast (October)

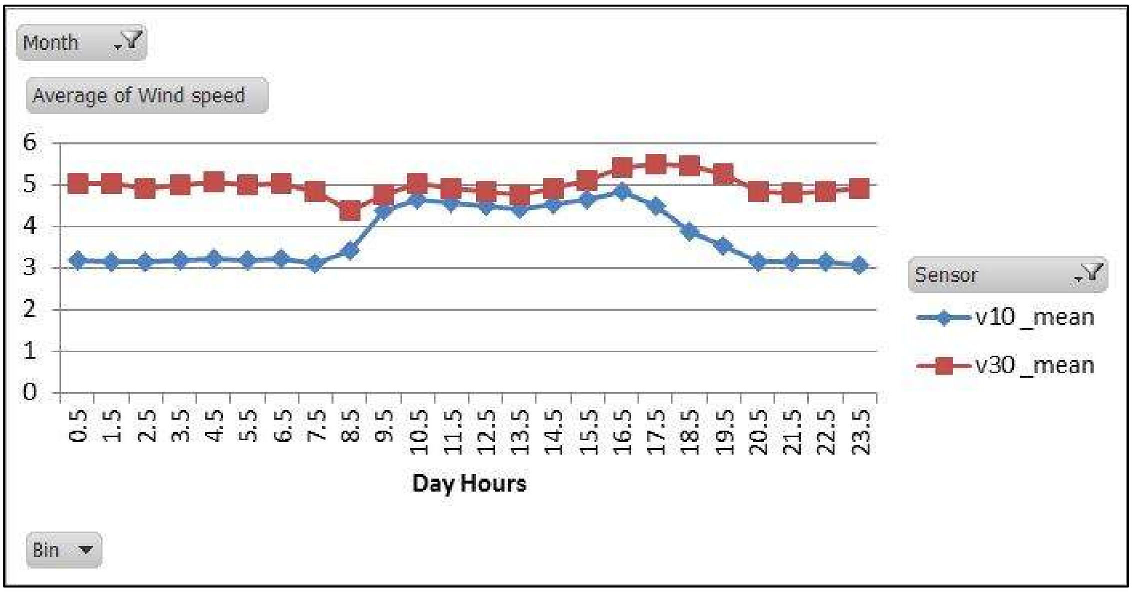


Figure 3.27: Diurnal Wind Speed Variation at Zorlu Mast (November)

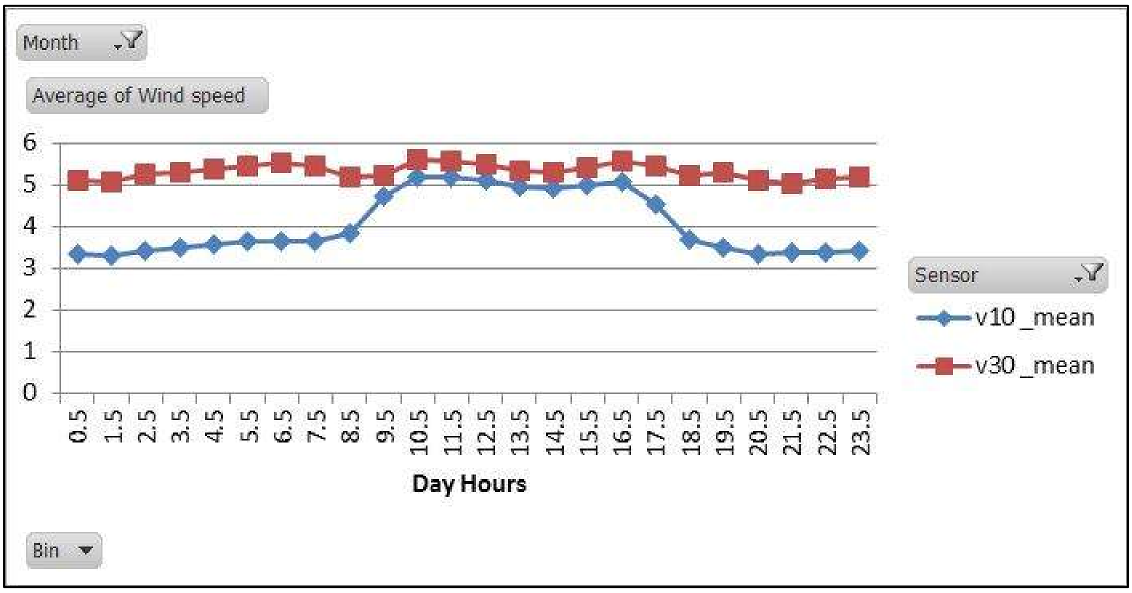


Figure 3.28: Diurnal Wind Speed Variation at Zorlu Mast (December)

3.6.5 Annual Diurnal Average Wind Speed

Figure 3.29 shows the Diurnal variation of wind speed, for the wind data recoded during the period of March 2007 to November 2009, at 85, 60, 30, and 10m levels. The seasonal Diurnal variations are presented below. The Diurnal trend shows that the wind speed starts decreasing at 900 hrs up to 1300 hrs and after the wind speeds get the increase and reaches to maximum between 1800 hrs and 1900 hrs in the evening.

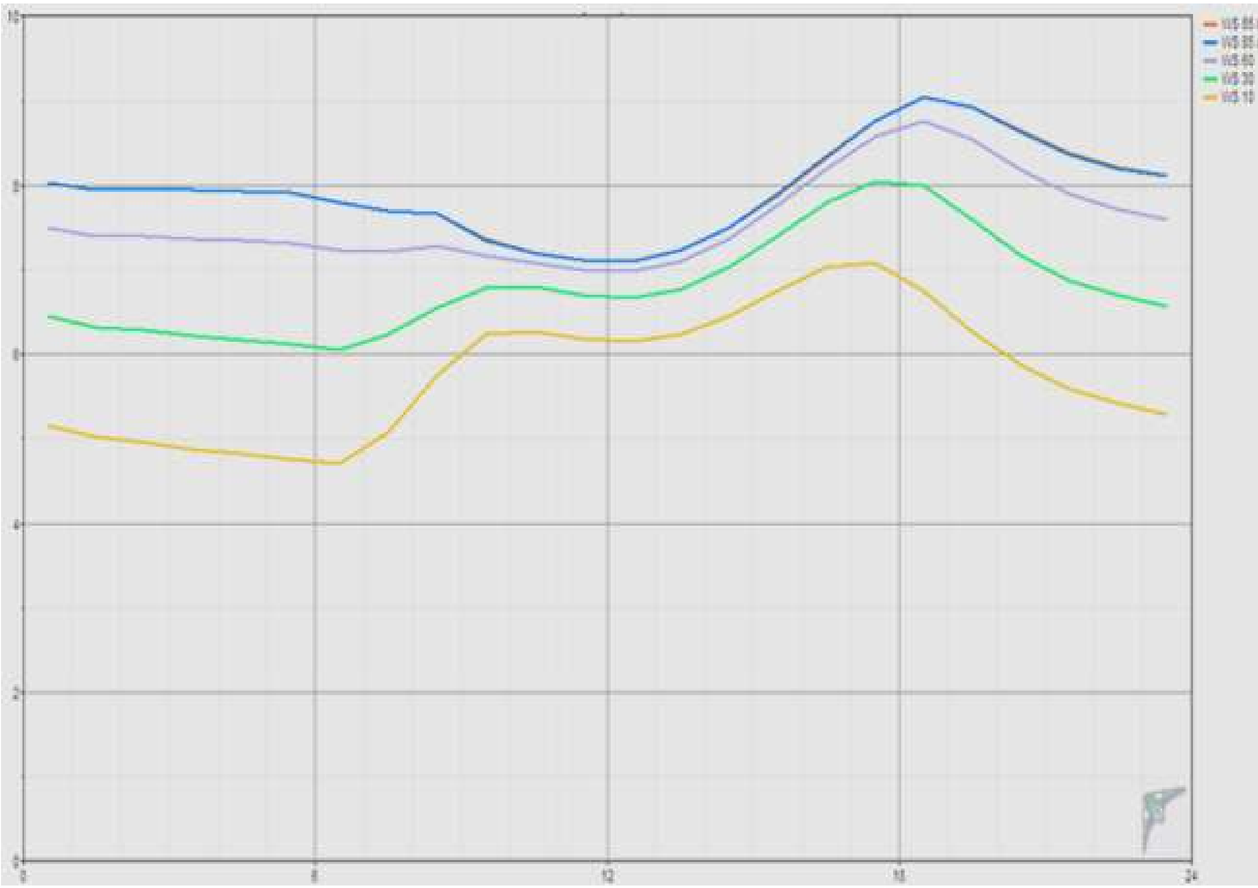


Figure 3.29: Annual Diurnal Wind Speed Variation at Zorlu Mast

3.6.6 Wind Rose

Wind Rose using data from wind vane installed at 80m height is presented in **Figure 3.30**, the predominant wind direction is toward southwest direction.

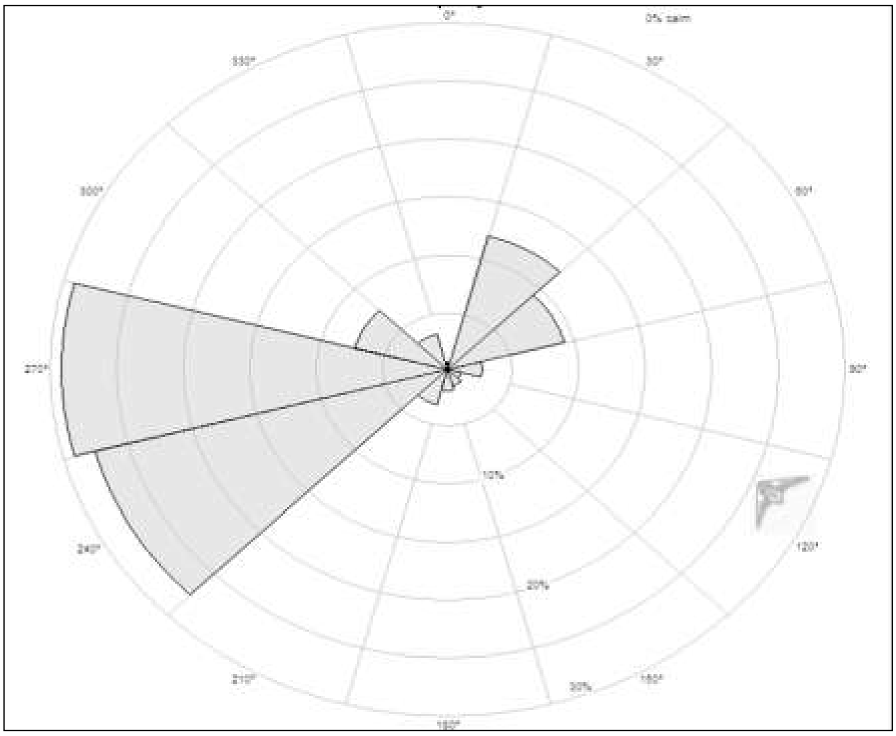


Figure 3.30: Wind Direction Frequency Distribution at Zorlu Mast at 80m

3.6.7 Long term Wind Speed

From all above analysis, it is proved that Zorlu mast is installed as per required IEC 61400-12 standard. Results obtained from the mast are in line with the expected patterns. To further establish the long-term wind regime in the region, long-term analysis is considered.

Generally, long-term analysis is carried out to compare short-term data with long-term data. Comparison is carried out in first stage by calculating a correlation. If a good correlation is observed between short-term on-site data and long-term data, long term wind speed is calculated.

For establishing long-term wind speed in the Jhimpir area, author considered Hyderabad Airport. Duration of airport data considered is 2000 to 2009. Ten (10) years of data is as per the standard practices. Concurrent periods of Hyderabad and Zorlu data are overlapped and correlation has been created with varying intervals as shown in **Figure 3.31**. Sensitivity analysis was carried out in which slope and intercept are carefully observed for each changing interval. It is found that correlation between two datasets is 83% with interval period of 5 days.

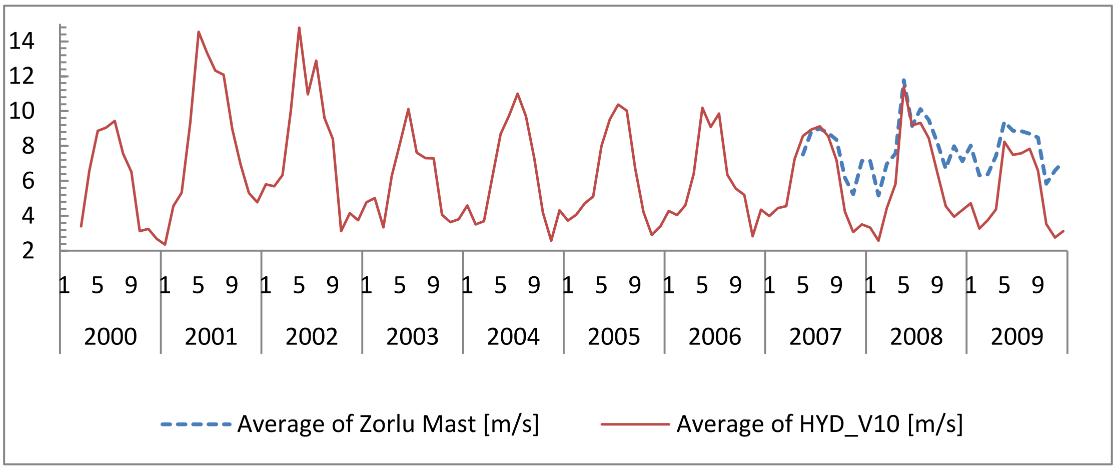


Figure 3.31: Co-relation of Hyderabad Data and Zorlu Data (2000-2009)

Using the linear correlation, long term average wind speed calculated to be 8.07 m/s. while performing the sensitivity analysis, it is found that differential of 3% can be observed. It also shows long-term wind speed in the region is high as compared to measured wind speed.

3.7 Comparison of Reliable & Unreliable Wind Data

After analysis of two masts, a comparison is carried out and monthly mean wind speeds are compared.

3.7.1 Monthly Mean Wind Speeds

Monthly mean wind speeds are calculated in above section for the Nooriabad and Zorlu Mast. Average wind speeds of both mast are presented in **Figure 3.32.** It shows the difference of Monthly Mean Wind speeds between Nooriabad met data and Zorlu met data. It shows that the Nooriabad met mast shows low wind speeds in the month of June, July and August, which are considered as the most windy months of the year in those areas, whereas shows high wind speeds during the month of January, which are the low wind speed months.

From below figure, it can be observed that Zorlu met mast-showing consistency of wind speeds. Patterns are in line with the expected regime in the area. Whereas wind speeds predicted from Nooriabad are close to the Zorlu mast. However, wind patterns are not very much convincing.

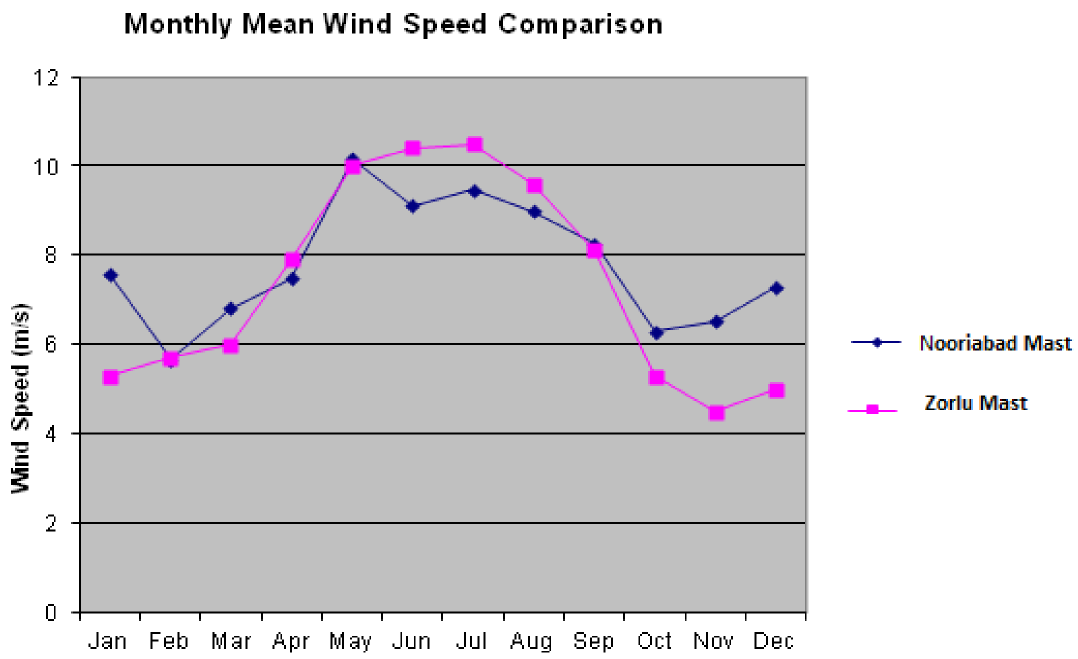


Figure 3.32: Monthly Mean Wind Speed Comparison

3.8 Conclusion of Analysis between Unreliable and Reliable Mast

- Data from Reliable masts and Unreliable masts were gathered and processed for the comparison. The results of the comparison are as below;
- Comparison of two masts are done and trends are mainly in line with each other
- From the comparison of final results, it can be extracted that differential in annual wind speed between Unreliable mast (Nooriabad mast) and Reliable mast (Zorlu) are approximately 08% to 12%
- Main reason of differential in wind speeds is due to non-compliant installation and non-standardized maintenance of masts.
- Quality of data from unreliable mast is objectable but its duration is longer.
- Quality of data from reliable mast is good but duration of data from the mast is short to perform a bankable wind study.
- To build the confidence on wind regime, it is required to introduce monthly guaranteed wind speed. This guaranteed wind speed are termed as benchmark wind speed.
- Benchmark wind speed is a safe estimation that should be acceptable to project developers, lenders and also in the interest of purchasers in terms of financials and development of wind power projects in Pakistan.

CHAPTER 4 : PROPOSED METHODOLOGY TO MITIGATE RISK ASSOCIATED WITH UNRELIABLE WIND MASTS

4 Proposed Methodology to Mitigate Risk Associated with Unreliable Wind Masts

The absence of historical and reliable wind data was a major impediment in the realization of wind power projects in Pakistan. The absence of long-term bankable wind data, the available short-term wind data from PMD met masts not in compliance with international standard and inferior quality equipment installed by private sector entities contributed to the lack of reliability.

In order to overcome the situation with the available set of information, i.e. the wind data gathered from the PMD masts, an innovative concept of "*Wind Risk*", simply defined as the *risk associated with the variability of wind speed* was introduced. According to this concept the power purchaser, the Government of Pakistan would bear all risk of variations in the *wind speeds* from specified' benchmark wind speeds', established on the basis of wind data collected from the reference masts (PMD met masts) for the respective areas.

Power production from the wind turbines is a function of wind speed, wind direction, air density, and topography of the area etc. The dominant parameter effecting wind turbine production is however, the wind speed. It is therefore suggested that the "*Wind Risk*" should only cater for variations in the wind speeds. In this way, the Government would be underwriting the wind data from the PMD masts and covering all the down side differential, if any, between the actual wind speeds and the wind speeds benchmarked on the basis of PMD wind data. In simple words, Government / purchaser will pay the difference of energy payments because of lower wind speeds than benchmark wind speeds. In this way, the investor would not have to face any loss of revenues and ultimately the loss in return on their investment occurring because of lower energy production due to lower wind speeds against the predictions made based on available wind data. This innovative concept was accepted and announced by Government and has been incorporated in the Policy for Development of Renewable Energy for Power Generation 2006 [56]. As a proof in this regard, a certificate by AEDB, Government of Pakistan is attached as Annexure-II to this thesis.

All private investors developing wind power projects based on wind data available from PMD masts have been offered "*Wind Risk*" coverage and it has been made mandatory for power purchaser to buy all the power generated from these projects.

The "*Wind Risk*" concept revolves around the idea that the project must not suffer financially in case of lower energy production due to average wind speeds being low, as compared to the established Benchmark Wind Speed at hub height.

4.1 Concept of Wind Risk

The "Wind Risk" concept involves setting up of monthly and annual 'wind speed benchmarks' from the available set of wind data gathered from the PMD masts, on which the Government provides its guarantee. These wind speed benchmarks would be used by the project developer for estimating energy production from the project, and developing energy production benchmarks. During operation of the project, the energy payments to the project sponsor will be based on the actual energy production from the wind farm. In case of lower energy production due to lower wind speeds as compared to the benchmark wind speeds, the project sponsor would be paid upto the benchmark energy production for that particular month thus covering for the energy not produced due to low wind speeds. Thus, the project sponsor is paid for all the energy produced during that month and for the unproduced energy of a month due to shortfall in wind speed.

In order to record the actual free stream wind velocity during the operational month, a wind measuring protocol has been designed, with the consultation of the author based on the IEC (International Electro Technical Committee) requirements. The actual free stream wind speed recorded by this protocol will be compared against the established benchmark wind speeds in order to calculate the "Wind Risk" for the operational month of the wind farm.

4.2 Wind Speed Benchmarking

The unavailability of bankable/reliable long-term wind data has raised many doubts for the wind farm developers. Wind measurement masts installed by PMD in 2002 had inherent flaws in their installation. The use of the locally calibrated sensors & data loggers added to the uncertainty of the wind speed data obtained from the PMD masts. Upon recognizing, the questionable reliability of the available wind data, an innovative "*Wind Risk*" concept was thus introduced which has later been incorporated to the Renewable Energy Policy of the GoP. Under "*Wind Risk*" concept, the investors/ project developers are protected against the risk of variability of wind speed. Under this concept, Benchmark wind speeds have been developed and are under-written by the GoP to develop the wind market on a fast track. The "*Wind Risk*" concept has also been incorporated into the security packages to be signed between the IPPs and the purchaser i.e. GoP; whereby monthly payments of purchase of power are made in accordance with the benchmark wind speed table. Therefore, development of accurate benchmark wind speeds is the key to success of the whole concept. The Benchmark Wind Speeds at different hub heights for different regions were developed by the author [55] and then have been reviewed and verified by RISO National Laboratory of Denmark. The development of Benchmark wind Speeds is considered as the most important feature of "*Wind Risk*" concept.

The wind data gathered from Gharo met mast, located on the southeast outskirts of Gharo town bearing coordinates 24º 44.307' N and 67º 36.423' E, has been used for developing the benchmark wind speeds for Gharo region. For the analysis, wind data recorded at 30m height for the period of January 2003 to May 2005, provided by the Pakistan Meteorological Department, has been used.

The Wind data gathered from Nooriabad met mast, located approximately 84 km north-east of Karachi bearing coordinates 25 º 10.906' N 67º 48.719' E , has been used for developing the benchmark wind speeds for Jhimphir region.

The Nooriabad mast has been recording wind data at 10 m and 30 m since April 2002. In October 2005, a new Anemometer was installed at a height of 50 m, which has been recording data since then. For analysis, wind data recorded at 10 m and 30 m height for the period of four years (2003 - 2006), provided by the Pakistan Meteorological Department, has been used.

4.2.1 Approach /Methodology

Mean wind speed values have been calculated at 30m level data at reference sites, which have been further extrapolated to different hub heights using the power law. The same raw wind data is then loaded in to Wind Atlas analysis and Application Program (WAsP) to predict wind speeds at locations away from the reference site (eg. potential wind farm site), at different hub heights. The wind data is then analyzed, using WAsP, and estimates of energy production are obtained. The methodology of development of benchmark wind speeds is given in the flow chart in **Figure 4.1**.

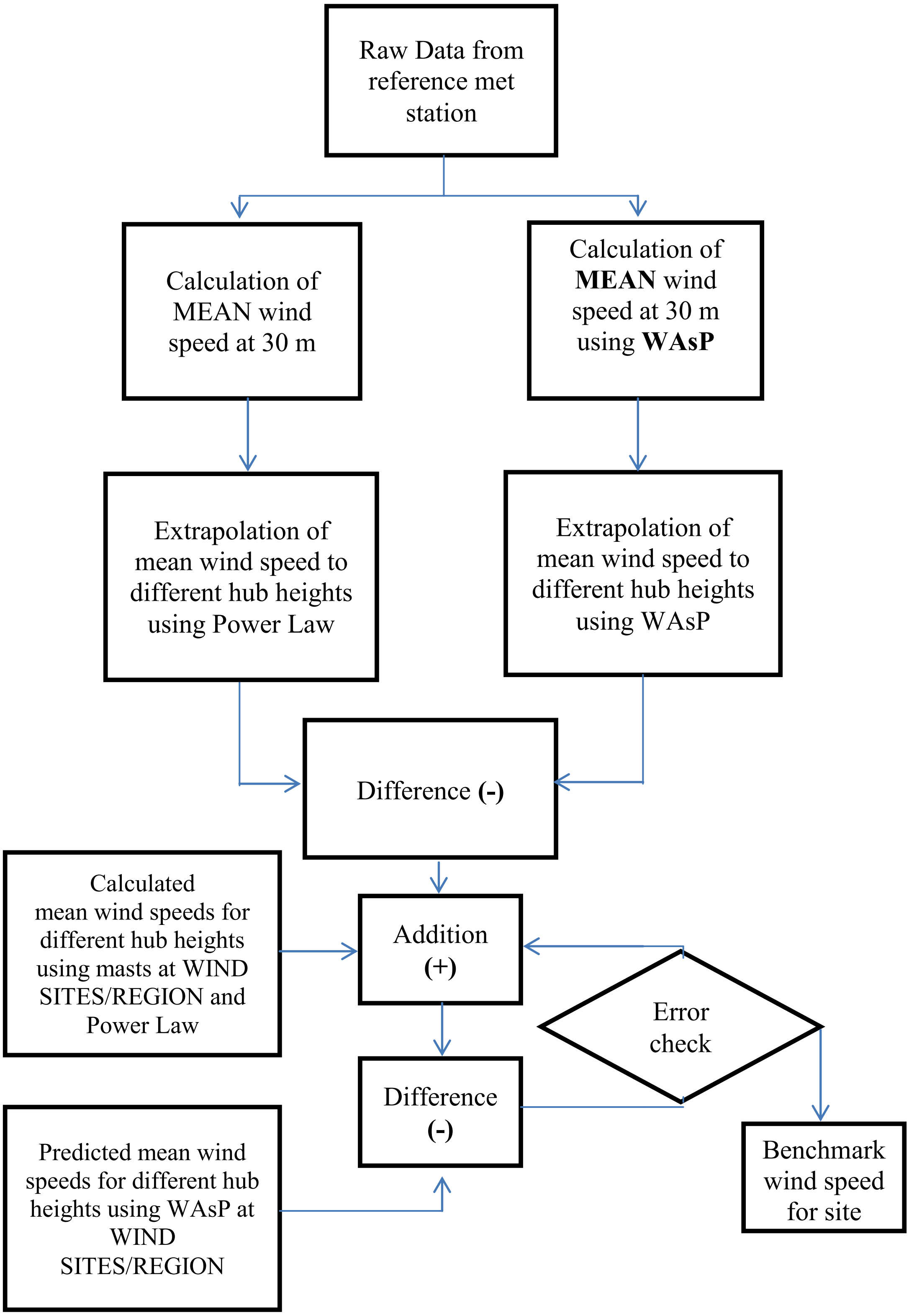


Figure 4.1: Benchmark Wind Speed Determination

4.2.2 Result Analysis – The Wind Speed Benchmarks

The Monthly Benchmark Wind Speeds for wind farm sites, based on the wind data gathered at Gharo mast and Nooriabad masts, established using the above approach are presented in **Table 4.1**, **Table 4.2**.

These benchmark values along with the approach used for establishing the benchmarks, formally accepted by AEDB, have been reviewed and verified by RISO National Laboratory of Denmark further and agreed upon by the different stakeholders from Government for "*Wind Risk*".

It should be noted that the conservative approach has been taken by considering the lowest values of mean wind speeds for benchmarking, i.e. the wind speed values on which Government of Pakistan (GoP) would bear the "*Wind Risk*". Factors contributing to the inaccuracies in this approach include, sensors not complying with IEC standards, sensor losses, obstacle around the masts, inferior logging equipment, and unavailability of latest topographical maps.

The discrepancy in the wind speed measurements is evident from the monthly mean wind speed values recorded at different heights for Gharo met mast, which are presented in **Table 4.3**. It is to be noted that the 10m and 30m average wind speed values are calculated using the four-year data where as the 50m average values are calculated on one complete year 2006 data. The anemometer at 50m level was installed in September 2005. It can be seen from the **Table 4.3** that the recorded monthly mean wind speed values for 2006 at 50 m height are different from the extrapolated values for 50m using 2003-2006 data. The difference in the monthly recorded and extrapolated values is primarily due to the reduced span of recorded wind data and distortion of values from sensor at 50m level since due to installation in close proximity of one leg of lattice tower.

Table 4-1: Monthly Benchmark Wind Speeds for Gharo

Month	Monthly Benchmark Wind Speed				
	30m	**50m**	**60m**	**67m**	**80m**
January	4.7	5.1	5.2	5.3	5.4
February	5.1	5.4	5.5	5.6	5.7
March	5.3	5.7	5.8	5.9	5.9
April	7.0	7.3	7.4	7.6	7.6
May	8.9	9.4	9.6	9.7	9.8
June	10.3	10.9	11.1	11.2	11.3
July	8.4	8.9	9.0	9.2	9.2
August	9.3	9.8	10.0	10.2	10.3
September	7.6	8.1	8.2	8.3	8.4
October	4.3	4.6	4.7	4.7	4.8
November	3.8	4.1	4.2	4.3	4.4
December	4.6	4.9	5.1	5.2	5.3
Annual Average	**6.6**	**7.0**	**7.1**	**7.2**	**7.3**

For wind turbine with hub heights in the 80m region, **Table 4.1** suggests production at, or very close to, full capacity. In addition, the winter months may prove to be the months of lower production. The wind farms may enjoy the benefits of loss of minimal production should they schedule the bulk of the operation and maintenance activities in the winter months.

Table 4-2: Monthly Benchmark Wind Speeds for Jhimphir sites.

Month	**Monthly Mean Wind Speeds (m/s)**				
	30m	**50m**	**60m**	**67m**	**80m**
January	4.25	4.70	4.90	5.02	5.24
February	4.50	4.98	5.18	5.32	5.55
March	4.77	5.28	5.50	5.64	5.89
April	6.39	7.03	7.29	7.46	7.75
May	8.29	9.05	9.36	9.56	9.90
June	8.79	9.50	9.78	9.96	10.25
July	8.83	9.59	9.89	10.08	10.40
August	8.20	8.89	9.16	9.34	9.63
September	6.63	7.28	7.54	7.72	8.01
October	4.22	4.68	4.87	5.0	5.22
November	3.59	3.98	4.14	4.24	4.43
December	3.96	4.38	4.56	4.67	4.88
Annual Average	**6.0**	**6.6**	**6.8**	**7.0**	**7.3**

The wind speeds for the Jhimpir region, as presented in **Table 4.2**, are fairly close to the speeds in the Gharo region. Wind farms sponsors may pick either region of the two regions without suffering a large penalty in terms of energy production.

Table 4-3: Monthly mean wind speeds recorded at Gharo mast

Month	**Monthly Mean Wind Speed (m/s)**				
	2003-2006			**2006**	
	Measured 10m	**Measured 30m**	**50m-Extrapolated Values**	**Measured 50m**	**50m-Extrapolated values (w.r.t 30m records)**
January	1.8	3.6	4.2	4.5	4.4
February	2.4	3.9	4.4	4.9	4.2
March	2.3	4.2	4.8	5.2	5.3
April	4.2	5.9	6.6	6.9	7.0
May	5.9	7.5	8.4	9.8	9.1
June	6.1	8.5	9.4	8.2	8.2
July	5.9	7	8	8.8	9.1
August	5.7	8.1	9	7.4	7.3
September	4.3	6.4	7.2	5.0	4.8
October	2.1	3.4	3.9	5.1	4.3
November	1.3	3	3.5	3.6	3.4
December	1.7	3.5	4.1	4.8	3.5
Mean of Means	**3.7**	**5.4**	**6.1**	**6.2**	**5.9**

The mean wind speeds calculated from the wind data gathered at 30 m have been extrapolated to different heights by using the (a) 'Power Law' [55] and (b) Wind shear formula.

4.2.3 Validation of Benchmark Wind Speeds by Comparison of Annual Energy Production of Unreliable and Reliable Mast

After comparing the wind speeds, annual energy is predicted from two mast on the same lands and same micrositing. Turbine Vestas (V90) turbines is used for energy prediction

For the production estimation, WAsP software is used. Power curve of turbine is introduced in software along with turbine power curve, topographical map and wind data and results of WAsP simulations are compared.

Results generated for the simulations are given in **Table 4.4.**

Table 4-4: Energy Yield Prediction at Benchmark Wind Speed using Wind Data of Nooriabad Mast for Vestas

Gross AEP (GWh)	173.74
Wake Losses (%) - (GWh)	11.05
Net Electrical Output of Wind Farm - (GWh)	162.69
Availability (97%) - (GWh)	4.88
Power Curve Density correction Losses (3.5%) - (GWh)	5.69
Electrical Losses (3%) - (GWh)	4.88
Scheduled maintenance/ Miscellaneous (1.0%) - (GWh)	1.62
Blade Degradation (0.5%) - (GWh)	0.81
P50 Wind Farm Yield (GWh/annum)	144.79
P50 Capacity Factor (%age)	32.80

The below **Table 4.5** shows the detail predictions of Energy Yield Calculations at Benchmark Wind Speed of all twenty eight (28) wind turbines of Vestas, V90;

Table 4-5: Energy Yield Calculations at Benchmark Wind Speed using Wind Data of Nooriabad Mast for Vestas

Energy Yield Prediction at Benchmark Wind Speed using the Wind Data of Nooriabad Mast								
Vetas V90-1800 kW								
Site	**X-location [m]**	**Y-location [m]**	**Elevation. [m]**	**Height [m]**	**Wind Speed (U) [m/s]**	**Gross AEP [GWh]**	**Net AEP [GWh]**	**Loss [%]**
Turbine 01	399883.8	2773718	42	80	7.24	6.144	6.002	2.3
Turbine 02	399486.4	2773987	40	80	7.23	6.136	5.953	2.97
Turbine 03	399088.9	2774256	45	80	7.24	6.155	5.962	3.14
Turbine 04	398691.5	2774525	51	80	7.28	6.187	5.995	3.1
Turbine 05	398294.1	2774794	53	80	7.29	6.198	6.008	3.07
Turbine 06	397896.6	2775063	54	80	7.3	6.204	6.023	2.92
Turbine 07	397499.2	2775333	56	80	7.3	6.203	6.084	1.92
Turbine 08	399911.6	2774275	48	80	7.31	6.218	5.796	6.79
Turbine 09	399514.1	2774545	49	80	7.29	6.204	5.751	7.3
Turbine 10	399116.7	2774814	51	80	7.31	6.238	5.781	7.32
Turbine 11	398719.3	2775083	54	80	7.29	6.201	5.741	7.42
Turbine 12	398321.9	2775352	56	80	7.3	6.208	5.749	7.39
Turbine 13	397924.4	2775621	57	80	7.31	6.209	5.789	6.76

Turbine 14	399939.4	2774833	52	80	7.32	6.233	5.69	8.71
Turbine 15	399541.7	2775102	53	80	7.31	6.226	5.659	9.11
Turbine 16	399144.2	2775371	54	80	7.3	6.21	5.63	9.35
Turbine 17	398746.7	2775640	56	80	7.31	6.212	5.608	9.72
Turbine 18	398349.2	2775909	57	80	7.3	6.207	5.608	9.66
Turbine 19	397951.7	2776178	58	80	7.31	6.209	5.75	7.39
Turbine 20	398725.1	2776373	57	80	7.31	6.214	5.626	9.47
Turbine 21	398967.1	2776788	58	80	7.31	6.218	5.551	10.72
Turbine 22	399209.2	2777202	58	80	7.32	6.223	5.674	8.82
Turbine 23	398040.8	2776842	59	80	7.32	6.218	5.996	3.57
Turbine 24	398905.2	2777424	59	80	7.31	6.215	5.775	7.08
Turbine 25	398531.3	2777667	59	80	7.31	6.212	5.919	4.72
Turbine 26	397601.9	2775869	57	80	7.3	6.204	6.039	2.66
Turbine 27	398315.4	2777209	59	80	7.32	6.221	5.816	6.51
Turbine 28	398350.2	2776565	58	80	7.31	6.217	5.712	8.13
Energy Yield Prediction at Benchmark Wind Speed using the Wind Data of Nooriabad Mast					**7.30**	**173.74**	**162.69**	**6.36**

Figure 4.2 indicates the micrositing layout of Vestas turbine placed on land of Master land which is an assumed land for the analysis of both Nooriabad and Zorlu.

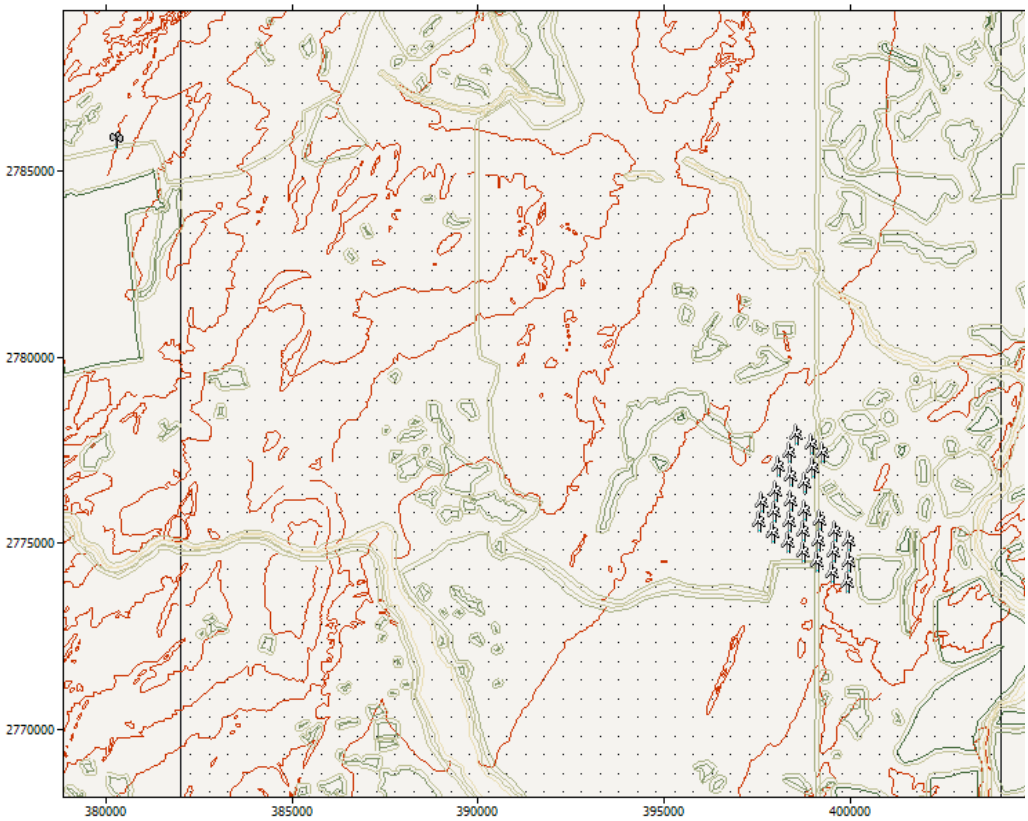


Figure 4.2: Micrositing of Vestas at Master Land – Nooriabad Data

To verify the analysis done on the Nooriabad mast, the author performed the same calculations for AEP considering the wind data of Zorlu met a mast, which is installed as per IEC standards. The calculation were done on the same WTG of Vestas V90 model of 1800 kW capacity assuming the same land for micrositing as taken in the Nooriabad analysis.

Presented below is the summary for Energy yield predictions at benchmark wind speed using data of Zorlu mast with Vestas turbine.

Table 4-6: Energy Yield Prediction at Benchmark Wind Speed using Wind Data of Zorlu Mast for Vestas

Gross AEP (GWh)	198.80
Wake Losses (%) - (GWh)	17.92
Net Electrical Output of Wind Farm - (GWh)	180.88
Availability (97%) - (GWh)	5.43
Power Curve Density correction Losses (3.5%) - (GWh)	6.3308
Electrical Losses (3%) - (GWh)	5.4264
Scheduled maintenance/ Miscellaneous (1.0%) - (GWh)	1.8088
Blade Degradation (0.5%) - (GWh)	0.9044
P50 Wind Farm Yield (GWh/annum)	160.98
P50 Capacity Factor (%age)	36.46

Table 4.7 shows the detailed Energy Yield Calculations at Benchmark Wind Speed using Zorlu met mast data for all twenty eight (28) Vestas V90 wind turbines;

Table 4-7: Energy Yield Prediction at Benchmark Wind Speed using Wind Data of Zorlu Mast for Vestas

Energy Yield Prediction at Free Flow Wind Stream using the Wind Data of Zorlu Mast								
Vetas V90-1800 kW								
Site Description	**X-location [m]**	**Y-location [m]**	**Elev. [m]**	**Ht [m]**	**U [m/s]**	**Gross AEP [Wh]**	**Net AEP [Wh]**	**Loss [%]**
Turbine 01	399883.8	2773718	42	80	7.23	6.872	6.726	2.12
Turbine 02	399486.4	2773987	40	80	7.25	6.916	6.654	3.79
Turbine 03	399088.9	2774256	45	80	7.27	6.944	6.669	3.96
Turbine 04	398691.5	2774525	51	80	7.32	7.037	6.759	3.94
Turbine 05	398294.1	2774794	53	80	7.37	7.114	6.807	4.32
Turbine 06	397896.6	2775063	54	80	7.38	7.141	6.814	4.58
Turbine 07	397499.2	2775333	56	80	7.39	7.152	6.861	4.06
Turbine 08	399911.6	2774275	48	80	7.3	6.997	6.217	11.14
Turbine 09	399514.1	2774545	49	80	7.31	7.014	6.199	11.61
Turbine 10	399116.7	2774814	51	80	7.32	7.028	6.212	11.62
Turbine 11	398719.3	2775083	54	80	7.37	7.115	6.285	11.66
Turbine 12	398321.9	2775352	56	80	7.38	7.133	6.236	12.57
Turbine 13	397924.4	2775621	57	80	7.39	7.151	6.296	11.95
Turbine 14	399939.4	2774833	52	80	7.34	7.081	6.07	14.28
Turbine 15	399541.7	2775102	53	80	7.34	7.071	6.042	14.55
Turbine 16	399144.2	2775371	54	80	7.33	7.045	6.013	14.65
Turbine 17	398746.7	2775640	56	80	7.37	7.13	6.073	14.82
Turbine 18	398349.2	2775909	57	80	7.38	7.134	5.957	16.5
Turbine 19	397951.7	2776178	58	80	7.39	7.158	6.426	10.24
Turbine 20	398725.1	2776373	57	80	7.38	7.14	6.169	13.6
Turbine 21	398967.1	2776788	58	80	7.38	7.14	6.14	14

Turbine 22	399209.2	2777202	58	80	7.35	7.088	6.45	8.99
Turbine 23	398040.8	2776842	59	80	7.39	7.162	6.803	5.01
Turbine 24	398905.2	2777424	59	80	7.39	7.156	6.528	8.77
Turbine 25	398531.3	2777667	59	80	7.45	7.267	7.174	1.29
Turbine 26	397601.9	2775869	57	80	7.39	7.158	6.862	4.13
Turbine 27	398315.4	2777209	59	80	7.47	7.294	6.884	5.63
Turbine 28	398350.2	2776565	58	80	7.39	7.165	6.556	8.51
Energy Yield Prediction at Free Flow Wind Stream using the Wind Data of Zorlu Mast					**7.36**	**198.80**	**180.88**	**9.01**

Figure 4.3 indicates the micrositing layout of Vestas turbine placed on land of Master land which is an assumed land for the analysis of Zorlu.

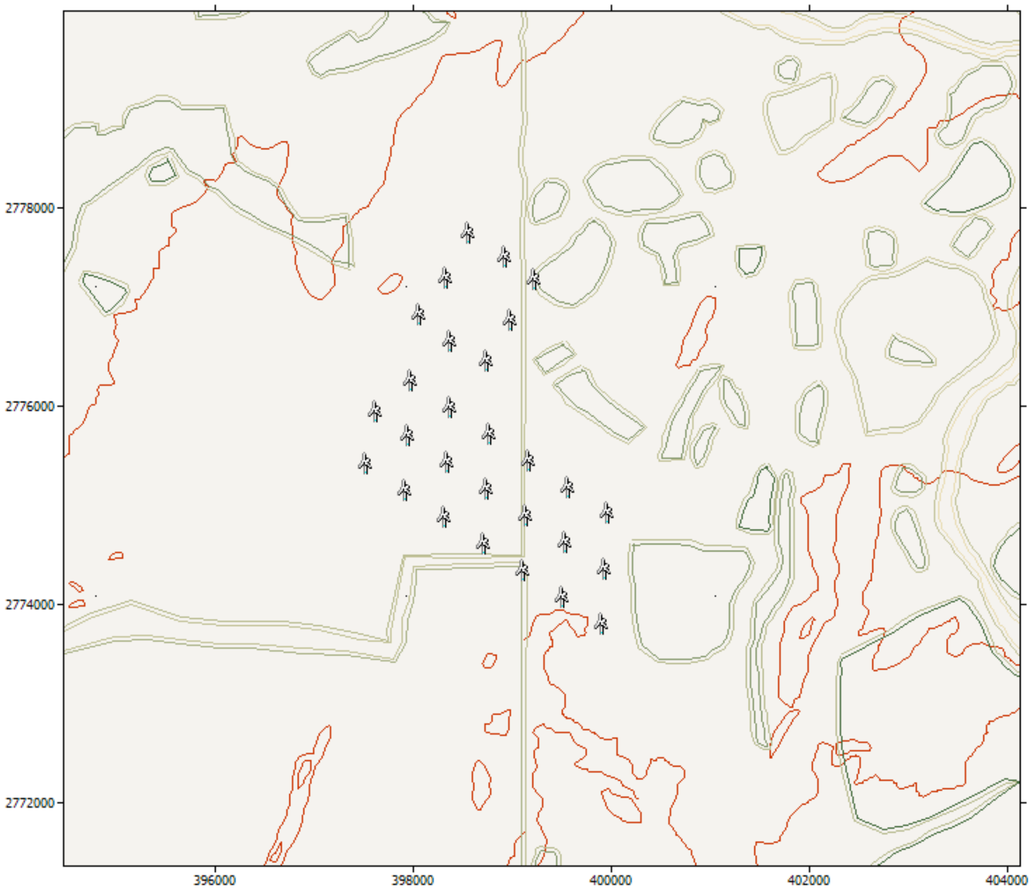


Figure 4.3: Micrositing of Vestas at Master Land – Zorlu Data

After comparing the energy production from two masts, it is observed that energy predicted from Zorlu mast is slightly higher than energy predicted from Nooriabad mast.

4.2.4 Capacity Factor at Nooriabad and Zorlu

Capacity factors calculated for the Wind farm at P50 from Nooriabad and Zorlu met data shows 3.66 % difference with each other. The capacity factor for Nooriabad met data was calculated as 32.8, while the capacity factor for Zorlu met data was 36.46. The capacity factor is the crucial information for the investors, as the net present return of a wind turbine is proportional to average capacity factor over the 20 years lifetime of wind farm.

From the comparison of wind data analysis of Nooriabad and Zorlu, it is found that Annual Energy Production and Capacity factor remain at lower end with unreliable wind data of Noorriabad. The reliable wind mast of Zorlu showed increase of 25.08 GWh in Annual Energy Production and capacity factor increase to about 4% as compared to Nooriabad.

4.2.5 Conclusion of Comparison Annual Energy Production of Unreliable and Reliable Mast

- Results obtained from Nooriabad mast and Zorlu mast found different.
- Difference of results shows requirement to introduce the concept of wind risk. Wind speeds finalized under the concept of wind risk may be reduced but guaranteed for the development of production. It will allow the development of projects on fast track.
- It has been found that all unreliable PMD meteorological masts are of similar kind therefore, suggestions and recommendations are general for all the unreliable meteorological masts. These recommendations are made in accordance to the international standard IEC-61400-12-1:2005 which is most significant in describing the optimal installation of wind masts and sensors.

    - Boom lengths should be changed and length of the boom should be 5.7 times the distance between two legs (side length) of lattice mast.
    - Top mounted boom anemometer should be replaced by the top mounted anemometer, and need to be installed 0.75 m high from the top of the mast.
    - Wind vane should be installed on separate boom and be at least 1.75m below the anemometer.

- Boom mounted anemometers must be separated from boom with the height of 12-15 times boom diameter.
- Circular booms are preferred and better than the existing square cross sectional booms.
- Height of measurement towers should be increased as the size of wind turbine is getting bigger with the passage of time. Increased heights of the towers will help to record the precise wind speed data at desired hub heights.
- With these inaccuracies in the data, coming from these wind mast and in the absence of long term bankable wind data the private sector was not able to cross the threshold of uncertainty when it came to invest their capital. Therefore author had introduces a very innovative concept of *"Wind Risk"* to cope with these discrepancies and mitigate the risk associated with the wind data. The detail concept with practical verification is given in **Chapter-4**.

4.3 Proposed Methodology for Translation of "Wind Risk" into Legal Contractual Agreements

The "*Wind Risk*" concept, introduced for the development of wind power projects in Pakistan and incorporated in the Policy for Development of Renewable Energy for power Generation 2006 by the Government [56], has been incorporated in the major contractual documents governing the implementation of wind power projects.

The tariff for wind power projects in Pakistan is determined using a 'Cost Plus' model [57]. The cost components incorporated in the model include the project costs, the debt servicing, operation & maintenance costs and a nominal return on equity, plus any other necessary cost(s) applicable to the project in question. Tariff for a wind power project is determined on the basis of the applicable cost components provided by the project sponsor and the estimated energy production from the project on the basis of wind speed benchmarks. The tariff, denominated in US cents power kWh, is determined on a benchmark energy production given by the project sponsor [57]. In case the energy production exceeds the benchmark energy production, the project sponsor will be paid a Bonus Energy Tariff (shown in this document as 10% of the determined tariff) for the energy in excess of the benchmark production level. For all the amounts of energy less than the benchmark energy, solely due to variation of wind speed from the benchmark wind speed, the investor is paid the full amount of tariff. The Energy Purchase Agreement (EPA) describes the "*Wind Risk*" structure in details and lays down the energy payment mechanism in detail.

4.3.1 The "Wind Risk" Structure

As per the *"Wind Risk"* structure, the project sponsor is required to provide the estimated energy productions corresponding to the wind speed benchmarks, termed as the Monthly Benchmark Energy, and power curve of the whole wind farm, Monthly Power Curve Energy. The structure divides the energy generated from a wind farm into three main categories of Regular Energy Payment, Shortfall Energy Payment and Bonus Energy payment.

The "*Wind Risk*" structure is shown in the **Figure 4.4**.

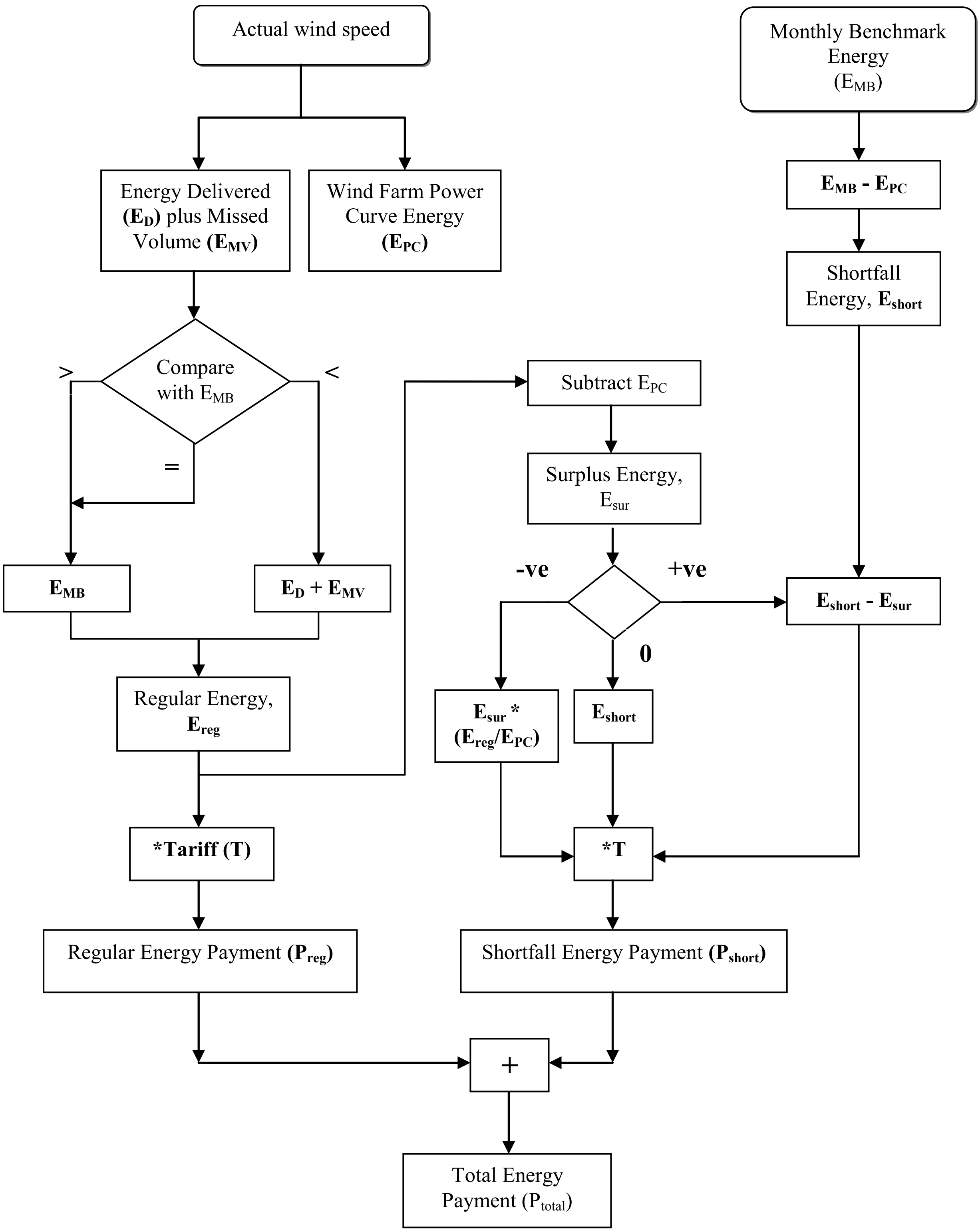


Figure 4.4: Benchmark Wind Speed Determination

4.3.1.1 Definitions

The structure divides the energy generated from a wind farm into several categories, for the sake of calculation of regular energy payments and the "*Wind Risk*" coverage, which are given here.

1. ***Monthly Benchmark Energy (E_{MB}):***

The Wind farm's Monthly Power Curve Energy (expressed in kWh) corresponding to the Monthly Benchmark Wind Speed for a given Month in a calendar year, as provided in Benchmark Energy Table.

2. ***Net Delivered Energy (E_D):***

The net electric energy expressed in kWh that is generated by the wind farm and delivered at the Interconnection Point, as measured by the Metering System.

3. ***Regular Energy (Ereg):***

For any Month, the sum of the quantity of Net Delivered Energy (E_D) and Energy due to Missed Volume (E_{MV}) less than or equal to the Monthly Benchmark Energy for that Month.

4. ***Energy due to Missed Volume Event (E_{MV}):***

The volume of Net Delivered Energy not delivered by the wind farm which non delivery is due solely to a Missed Volume Event, provided that, the generation and delivery of the Net Delivered Energy shall be resumed as soon as possible upon cessation of the relevant Missed Volume Event (except where prevented by another Missed Volume Event). The Missed Volume Event can be any of the following;

(i) Constraints on the Grid System,

(ii) Variations in Grid System Frequency outside the Technical Limits,

(iii) Grid System voltage outside the Technical Limits,

(iv) An Emergency, or

(v) Dispatch Instruction

5. Monthly Energy (Emonthly):

For any Month, the sum of Net Delivered Energy and the Non Project Missed Volume, ($E_{monthly} = E_D + E_{MV}$).

6. Shortfall Energy (Eshort):

The shortfall, if any, of the sum total of Net Delivered Energy and Non-Project Missed Volume in a given Month below the Monthly Benchmark Energy for that Month, where such shortfall is attributable solely to the Monthly Actual Wind Speed being less than the Monthly Benchmark Wind Speed.

$E_{short} = E_{MB} – E_{PC}$

7. Bonus Energy (Ebonus):

For any Month, the quantity of Monthly Energy that exceeds the Monthly Benchmark Energy for that Month

8. Wind Farm Monthly Power Curve Energy (E_{PC}):

The quantity of Net Delivered Energy the wind farm is capable of generation and delivery during a given Month at the Interconnection Point corresponding to each point (graded to one-tenth of a meter per second) on the spectrum of wind speed ranging from the Cut In Wind Speed to the Cut Out Wind Speed of the WTGs comprised in the wind farm.

9. Tariff (T):

Energy Price for the relevant month.

The nomenclature /abbreviations used in the next sections are given here for reference;

Where;

$P_{reg} = T \times E_{reg}$
$P_{bonus} = T \times E_{bonus} \times T_{bonus}$
$P_{short} = (E_{short} - E_{sur}) \times T$
$P_{short} = E_{short} * (E_{reg}/E_{PC}) \times T$
$E_{sur} = E_{reg} - E_{PC}$

P_{reg}	=	Regular Energy Payment for preceding Month
T	=	Energy Price for the preceding Month
T_{bonus}	=	Bonus Energy Tariff
E_{reg}	=	Regular Energy for the Month
E_D	=	Net Delivered energy for the preceding Month
E_y	=	Net Delivered Energy for the preceding Year
E_{MV}	=	Non- Project Missed Volume for the preceding Month
E_{MVy}	=	Non- Project Missed Volume for the preceding Year
E_{MB}	=	Monthly Benchmark Energy for the preceding Month
P_{bonus}	=	Bonus energy Payment for the preceding Year
E_{bonus}	=	Bonus Energy for the preceding Year
P_{short}	=	Shortfall Energy payment for the preceding Month
P_{short}	=	Shortfall Energy
E_{PC}	=	Wind farm Monthly Power Curve Energy corresponding to the Monthly Actual Wind Speed for the Month
E_{sur}	=	Wind farm Yield Surplus
ABE	=	The net Annual Benchmark Energy which is aggregate of the Monthly Benchmark Energy for the whole year

4.3.1.2 Methodology to measure Energy due to Missed Volume Event (EMV) in Absence of Grid

In order to calculate the net delivered energy by the wind farm during events when the wind farm is available for generation but the grid is unavailable, an Energy due to Missed Volume Event (E_{MV}) protocol has been designed by the author and presented in later sections.

The "*Wind Risk*" structure provides coverage for the quantum of energy, which is not produced up to the level of benchmark energy production due to lower wind speeds during the operation of the wind farm thus mitigating the risk incident upon the project developer. However, the non-availability of the national grid during the operation of the wind farm at any prevailing wind conditions poses another dire risk for the project developer since the energy produced by the wind farm cannot be delivered to the grid. For the mitigation of this risk, the author has developed a protocol for the Energy due to Missed Volume Event, E_{MV}, which has been accepted by the utility and the project developers. The key parameter for this protocol is the expected energy production during missed volume events, such as grid unavailability.

4.3.1.3 Energy due to Missed Volume Event (EMV)

The volume of Net Delivered Energy not delivered by the wind farm, the non delivery of which is due to a Missed Volume Event (MVE). Each of the following events or circumstances: Constraints on the Grid System, Variations in Grid System Frequency outside the Technical Limits, Grid System voltage outside the Technical Limits, an Emergency, or a Dispatch Instruction, qualify as a Missed Volume Event (MVE). In each case (i) being the proximate and direct cause of cessation or reduction of the generation of the wind farm, and (ii) not caused by the operating conditions at the wind farm or a fault or failure of any equipment or safety device comprised in the farm, calculated as follows:

$$\boldsymbol{E_{MV} = E_{PC} \times \left[\frac{(d_{MV,avg} + t_{start})}{T_m}\right] \times A_v} \quad \textbf{(01)}$$

where,

- E_{PC} is the Power Curve Energy of the wind farm corresponding to the Average MVE wind speed during the Missed Volume Event.

- In a general sense, the Power Curve Energy refers to the amount of energy the wind farm is capable of generating and delivering during a given month, measured at the point of interconnection, for a given wind speed between cut-in and cut-out of the WTGs in the wind farm.

- $d_{MV,\,avg}$ is the Weighted Average Duration of the Missed Volume Event's, which is calculated as the sum of the duration of each Missed Volume Event in a given month (in minutes) adjusted for the proportion of the total installed WTG's which had to be curtailed due to each such Missed Volume Event, calculated as in equation 2:

$$\boldsymbol{d_{MVE,avg} = \sum(t_{MVE} \times (\frac{NT_{MVE}}{T_{WTG}})} \quad \textbf{(02)}$$

  where:
  - t_{MVE} is the duration of each Missed Volume Event in a given month in minutes
  - NT_{MVE} the number of WTG's, effected by the Missed Volume Event, i.e WTGs that had their production curtailied, limited, or completely stopped.
  - T_{WTG} the total number of installed WTG's in the wind farm

- t_{start} is the time required for staggered start up of all of the WTGs for safe introduction to the Grid System in minutes, calculated as in equation 3:

$$\boldsymbol{t_{start} = N_{MVE} \times 60} \quad \textbf{(03)}$$

Where:

- N_{MVE} is the number of Missed Volume Events in a given month, in case of a single Missed Volume Event lasting the whole of the given month than the Number of Missed Volume Events in a given Month will be zero

- Av is the average availability factor of the wind farm during the Period, calculated as in equation 4:

$$A_v = (E_{Dp} + E_{MVP})/E_{PC} \quad \textbf{(04)}$$

Where:

- p is the period of twelve (12) calendar months prior to the given month, provided that if a Missed Volume Event occurs:

1. during the first month following the Commercial Operations Date (COD), then the period shall be from the Commercial Operations Date to the last hour immediately preceding the Missed Volume Event.

2. after the first month and before the completion of one year, then the period shall be from the Commercial Operations Date to the last completed calendar month prior to the Missed Volume Event.

- E_{Dp} is the Net Delivered Energy for the period (p) preceding the given Month;
- E_{MVp} is the Missed Volume Energy for the period (p) preceding the given month;
- E_{PC} is the Wind farm Monthly Power Curve Energy, corresponding to the Monthly Actual Wind Speed for the period (p) preceding the given month;

The maximum value of Availability factor shall be limited to 100%. An example of the E_{MV} protocol is presented at the **Annexure-I** where complete protocol is elaborated using assumed operational data for both the cases mentioned above that is immediately after COD and after completion of one year of operation.

4.3.2 Energy Payments

The energy payments, under the "*Wind Risk*" structure, are divided into three components depending upon the energy generated by the wind farm.

4.3.2.1 Regular Energy Payment

The Regular Energy Payment for the Regular Energy shall be calculated as follows:

$$\boldsymbol{P_{reg} = T \times E_{reg}} \qquad \textbf{(05)}$$

Where:

- P_{reg} = Regular Energy Payment for the preceding Month;
- T = Tariff
- E_{reg} = Regular Energy for the preceding Month, determined as follows:

$$\boldsymbol{E_{reg} = Min\ (E_{MB} \times (E_D + E_{MV})} \qquad \textbf{(06)}$$

Where:

- E_D = Net Delivered Energy for the preceding Month;
- E_{MV} = Non-Project Missed Volume for the preceding Month;
- E_{MV} = Monthly Benchmark Energy for the preceding Month; and
- $E_{monthly}$ = Monthly Energy for the preceding Month.

4.3.2.2 Bonus Energy Payment

Bonus Energy is calculated and given on yearly basis contrary to Shortfall Energy Payment, which is given on monthly basis. This is designed to give comfort to the utility that the complex has successfully operated with good efficiency over the whole year before claiming the performance bonus.

In the event Bonus Energy is established for a given year, the Bonus Energy Payment for that year shall be calculated as follows:

$$\boldsymbol{P_{bonus} = E_{bonus} \times T_{bonus}} \qquad \textbf{(07)}$$

Where:

- P_{bonus} = Bonus Energy Payment for the preceding year;
- E_{bonus} = Bonus Energy for the preceding year,
- T_{bonus} = Tariff for Bonus Energy. This is equals to 0.1 * T.

Bonus Energy for the preceding Year is determined as follows:

$$\boldsymbol{E_{bonus} = (E_{Dy} + E_{MV_y}) - ABE} \qquad \textbf{(08)}$$

where;

- E_{Dy} = Annual Net Delivered Energy
- E_{MVy} = Non Project Missed Volume for the preceding year
- ABE = The net annual benchmark energy which is aggregate of the monthly benchmark energy for the whole year

4.3.2.3 Shortfall Energy Payment

In the event Shortfall Energy is established for a given Month, the Shortfall Energy Payment for that Month shall be calculated as follows:

Case-1: Provided the value of the Wind farm Surplus Energy (E_{sur}) is a positive number (including zero):

$$\boldsymbol{P_{short} = (E_{short} - E_{sur}) \times T} \tag{09}$$

Where:

P_{short}	=	Shortfall Energy Payment for the preceding Month;
E_{short}	=	Shortfall Energy, computed as follows:

$$\boldsymbol{E_{short} = E_{MB} - E_{PC}} \tag{10}$$

Where:

- E_{MB} = Monthly Benchmark Energy
- E_{PC} = the Wind farm Monthly Power Curve Energy corresponding to the Monthly Actual Wind Speed for that Month;
- E_{sur} = the Wind farm Yield Surplus; and
- T = Energy Price for the preceding Month

Case-2: Provided the value of the Wind farm Yield Surplus is a negative number (below zero):

$$P_{short} = E_{short} \times E_{reg}/E_{PC} \quad \textbf{(11)}$$

Where:

- P_{short} = Shortfall Energy Payment for the preceding Month;
- E_{short} = Shortfall Energy for the preceding month
- E_{reg} = Regular Energy for the preceding Month
- T = Energy Price for the preceding Month and
- E_{PC} = the wind farm Monthly Power Curve Energy corresponding to the Monthly Actual Wind Speed for that Month.

The value of the wind farm energy Surplus shall be determined as follows:

$$E_{sur} = E_{reg} - EPC \quad \textbf{(12)}$$

Where:

- E_{sur} = the wind farm Surplus;
- E_{reg} = Regular Energy for the preceding Month, and
- E_{PC} = the wind farm Monthly Power Curve Energy corresponding to the Monthly Actual Wind Speed for that Month.

For the avoidance of doubt, the Monthly Energy Payment may include Bonus Energy Payment or the Shortfall Energy Payment, but not both.

CHAPTER 5 : RESULTS AND DISCUSSION

5 Results and Discussion

The thesis is mainly encompassing two customized issues. First of them is the establishment of wind speeds in the region based on reliable wind data. Whereas second issue is to establish the payment mechanism/policy framework in link with the wind speeds. A combined approach to address above two issues leads to the concept of benchmark and "*Wind Risk*" mechanism.

The methodology discussed in Chapter-4 to mitigate the risks associated with the unreliable wind data results in following three mechanisms;

- A "Wind Risk" mechanism to minimize the risk associated with unreliability of wind data for the developers / sponsors / lenders for the fast track development of wind energy (the details of "Wind Risk" has been discussed in detail in Section 4.1 of **Chapter-4**.
- The development of benchmark wind speeds which have been developed using the PMD data (the details of wind speed benchmarking are given in Section 4.2 of **Chapter-4**)
- The payment mechanism and formulae are developed to create the right balance between the supplier and purchaser so that the whole mechanism of "Wind Risk" shall be translated into the contractual agreements (The mechanism along with formulae are given in Section 4.3 of **Chapter-4**.

Regarding establishment of benchmark wind speeds, generally all countries established the wind industry has in hand wind resources assessment data in the form of wind atlas followed by on-site measurements for at least a year which is considered as the most reliable source of wind data. Therefore in those countries, investor's risk due to variable wind speed is less and investors take the wind risk and only start the development of wind farm when the risk is quantifiable. In case of countries like Pakistan, where there is no wind atlas or other source of wind data available, wind power investor is at high risk due to variable wind speeds and in turn receiving their payments which are directly link with the wind speed. Therefore wind industry cannot be started unless the reliable long term wind data can be made available which in turn quantify the risk.

Therefore, to handle the issue of variable wind speed and minimizing the risk factor for investors, benchmark wind speeds has been established. For the purpose of establishing the wind potential, data sources of PMD were available but the data of PMD masts was highly challengeable. In that particular case, it was required that risk of data reliability should be offset with the concept of guaranteed wind resources. Otherwise, no project feasibility could be bankable. If the benchmark speeds are too conservative, the tariff from wind will become too high and this is not a comfortable situation for the policy makers. If the benchmarks are too optimistic then there is a risk of paying the wind risk payments every month which utilities would not like to do on a consistent basis. Thus, developing the right benchmarks for the region is the key aspect for the success of the whole mechanism. Another important point discussed in the thesis is that while developing the benchmark wind speeds for any region one may be little conservative than optimistic. It is because the formula for bonus payment is developed in such a way that it only allows X % energy payments over benchmark energy of the relevant year at benchmark wind speed. If X is 10 then it means that even if wind speed benchmarks are little low and notional tariff may seem high at the start. The real tariff will be lower as 90% of the energy will be free on the grid over benchmark energy and real tariff shall be lower than the notional indicative tariff.

The combined approach of introducing a wind risk and the bonus energy, in the given wind regime of the region, shows that the ultimate tariff of wind power plants shall have a potential to reduce than originally predicted. The phenomenon of bonus energy is expected to hit frequently thus increasing the delivered energy at a reduced tariff. On the other hand, the possibility of applying wind risk is lower. By having both scenarios in place, a balance could be maintained and the whole system is acceptable to utilities and developers as it creates a WIN~WIN situation.

Energy yield calculations based on unreliable wind data and reliable mast data are calculated and compared using wind flow model and WAsP. Deviation was found in the resultant energy yield calculations being lower with unreliable wind data, which proves that unreliable wind data directly affect the project financing and is ultimately put the investor at higher risk.

The next critical step was to interlink the benchmark wind speeds with the mechanism of payments which was established and is made part of policy frame work. In this way, it is stated that the whole mechanism is encompassing the unique requirement and thus model developed in unique having no precedence of this model is observed other than in Pakistan.

In the next Section 5.1, the formulae developed in Chapter-4 for the complete *"Wind Risk"* payment mechanism is practically applied on actual wind data of 49.5 MW Wind farm of Zolu Enerji located in Jhimpir Sindh. The objective is to verify the concept and mechanism proposed by the author and to be used for future practice replications. However, since no wind farm has yet started its operations and therefore operational data is not available. Thus, energy data is assumed against actual Zorlu Wind Farm actual wind speeds. Monthly energy data numbers are assumed based on the predicted energy calculations on the WAsP software using actual wind speeds.

5.1 Sample Calculations

In this section sample, calculations have been done using actual wind speed data of 49.5 MW wind farm of Zorlu Enerji located in Jhimpir, Sindh Pakistan. This shall validate the whole concept for the practical usage using the formulae developed by the author.

Actual Monthly benchmark wind speed of Jhimpir and actual wind speed data of Zorlu Enerji wind farm is used in the calculations. Monthly benchmark energy and Wind Farm Power Curve values are calculated in WaSP software and is given in **Table 5.1**.

Since no wind farm including Zorlu Enerji is not operational, therefore the Net Delivered Energy and Energy due to Missed Volume are assumed for the calculations.

Using this basic data sample energy calculations have been done using the formulae developed by the author.

These assumptions and energy calculations are shown in **Table 5.2.** After that sample energy payment calculations have been done as given in **Table 5.3** using the data given in **Table 5.2** and assumed tariff of US Dollars 9.5 cents per kWh.

Table 5-1: Wind farm Power Curve Energy

Wind Speed Spectrum (m/s)	Wind farm Power Curve Energy (GWh)	Wind Speed Spectrum (m/s)	Wind farm Power Curve Energy (GWh)
3.5	1.9		
3.6	2.3	7.1	12.5
3.7	2.8	7.2	13
3.8	2.9	7.3	13.4
3.9	3.1	7.4	13.8
4	3.3	7.5	14.2
4.1	3.4	7.6	14.5
4.2	3.6	7.7	14.8
4.3	4	7.8	15.1
4.4	4.2	7.9	15.4
4.5	4.4	8	15.7
4.6	4.4	8.1	16
4.7	4.5	8.2	16.3
4.8	4.5	8.3	16.6
4.9	4.7	8.4	16.9
5	5	8.5	17.2
5.1	5.3	8.6	17.5
5.2	5.6	8.7	17.8
5.3	6	8.8	18.1
5.4	6.5	8.9	18.4
5.5	7	9	18.7
5.6	7.2	9.1	19
5.7	7.4	9.2	19.3
5.8	7.6	9.3	19.6
5.9	7.8	9.4	19.9
6	8.1	9.5	20.2
6.1	8.4	9.6	20.5
6.2	8.8	9.7	20.8
6.3	9.4	9.8	21.1
6.4	9.8	9.9	21.4
6.5	10.2	10	21.7
6.6	10.4	10.1	22
6.7	10.8	10.2	22.3
6.8	11.2	10.3	22.6
6.9	11.6	10.4	22.9
7	12	10.5	23.2

Table 5-2: Sample Energy Calculations based on "*Wind Risk*" concept

Month	Monthly Benchmark Wind Speed	Monthly Benchmark Energy	Monthly Actual Wind Speed	Wind Farm Monthly Power Curve Energy	Net Delivered Energy	Energy due to Missed Volume	Monthly Energy	Regular Energy	Bonus Energy	Shortfall Energy Possibility (Only positive values are the possible cases for shortfall Energy)	Shortfall Energy	Wind farm Yield Surplus
	m/sec	GWh	m/sec		GWh	GWh	GWh	GWh	GWh		GWh	GWh
	V_{MB}	E_{MB}	V_{actual}	E_{PC}	E_D	E_{MV}	$E_{monthly}$	E_{reg}	E_{bonus}		E_{short}	E_{sur}
							$E_D + E_{MV}$	Min.($E_{monthly}$, E_{MB})	(E_{Dy} + E_{MVy}) - ABE	V_{MB} - V_{actual}	E_{MB} - E_{PC}	Ereg - E_{PC}
January	5.2	5.6	7.6	14.5	15.1	0	15.1	5.6		-2.3	N/A	N/A
February	5.6	7.2	5.7	7.4	6.6	0	6.6	6.6	Bonus Energy is calculated on the yearly basis. Using above it comes to **26.7 GWh**	-0.2	N/A	N/A
March	5.9	7.8	6.6	10.4	10.4	0	10.4	7.8		-0.7	N/A	N/A
April	7.8	15.1	7.5	14.2	14.2	0	14.2	14.2		0.2	0.9	0
May	9.9	21.4	10.6	23.5	19	1	20	20		-0.7	N/A	N/A
June	10.3	22.6	9.1	19	22.9	0	22.9	22.6		1.2	3.6	3.6
July	10.4	22.9	9.5	20.2	20.2	0	20.2	20.2		0.9	2.7	0
August	9.6	20.5	8.9	18.4	21	0	21	20.5		0.7	2.1	2.1
September	8.0	15.7	8.1	16	16	0	16	15.7		-0.1	N/A	N/A
October	5.2	5.6	6.6	10.4	9.1	0.5	9.6	5.6		-1.4	N/A	N/A
November	4.4	4.2	6.3	9.4	9.2	0	9.2	4.2		-1.9	N/A	N/A
December	4.9	4.7	7.3	13.4	14.8	0	14.8	4.7		-2.4	N/A	N/A
		153.3			**178.5**	**1.5**		**147.7**	**26.7**			
		ABE - Annual Benchmark Energy			Annual Net Delivered Energy	Non Project Missed Volume for the preceding year			Bonus Energy on yearly basis			

Table 5-3: Sample energy payments calculations

Month	Energy Price (EPm) US $ per kWh	Regular Energy Payment (P_{reg}) US $		T bonus	$P_{bonus} = T_{bonus} \times E_{bonus} \times 10^6$	Shortfall Energy Payment (P_{short})	Total Energy Payment (P_{total}) US $
	T	$T \times E_{reg}$	$T \times E_{reg} \times 10^6$	T*0.1		$(E_{short}-E_{sur})$*T (For Positive Number including zero)	$P_{short}+P_{reg}+P_{bonus}$
January	0.095	0.532	532000	0.0095		N/A	532000
February	0.095	0.627	627000	0.0095		N/A	627000
March	0.095	0.741	741000	0.0095		N/A	741000
April	0.095	1.349	1349000	0.0095		85500	1434500
May	0.095	1.9	1900000	0.0095		N/A	1900000
June	0.095	2.147	2147000	0.0095		0	2147000
July	0.095	1.919	1919000	0.0095		256500	2175500
August	0.095	1.9475	1947500	0.0095		0	1947500
September	0.095	1.4915	1491500	0.0095		N/A	1491500
October	0.095	0.532	532000	0.0095		N/A	532000
November	0.095	0.399	399000	0.0095		N/A	399000
December	0.095	0.4465	446500	0.0095	253650	N/A	446500
Yearly Bonus Payment (P_{bonus})							253650
Grand Total (P_{total})							**14,627,150**

5.2 Discussion

In the month of January the Monthly Actual Wind Speed is the same as the Monthly Benchmark Wind Speed and the Regular Energy is same as Monthly Benchmark Energy therefore there is no case of Bonus Energy or Shortfall Energy and the Total Energy Payment is equal to the Regular Energy Payment.

In the month of February Monthly Actual Wind Speed is more than the Monthly Benchmark Wind Speed. Also the Net Delivered Energy is more than the Monthly Benchmark Energy. Therefore Bonus Energy is applicable and 10% of that is given in the month of February under Bonus Energy Payment over and above the Regular Energy Payment.

In the month of March the Monthly Actual Wind Speed is less than the Monthly Benchmark Wind Speed. This is the case for Shortfall Energy Payment over and above the Regular Energy Payment. Shortfall Energy is calculated keeping in view the efficiency of the plant by comparing the actual GWh delivered at Monthly Actual Mean Wind Speed with the Wind Farm Power Curve as in **Table 5.1**. In this case as the actual GWh are equal to what is supposed to be at that speed therefore efficiency is considered -100% and Shortfall Energy Payments are given in the month of March.

If consider the month of May there is some energy loss as seen in Enegy due to Missed Volume. This energy is added in the Net Delivered Energy to calculate the Monthly Energy. Another interesting point to note here is that as the Monthly Energy in May is more than the Benchmark Energy therefore the Regular Energy is taken as Benchmark Energy and is paid at full tariff. The rest of the energy is the Bonus Energy and is paid at 10% of the total tariff.

Graph shown in **Figure 5.1** will give the comparison between Benchmark Energy and Total Energy for the whole year.

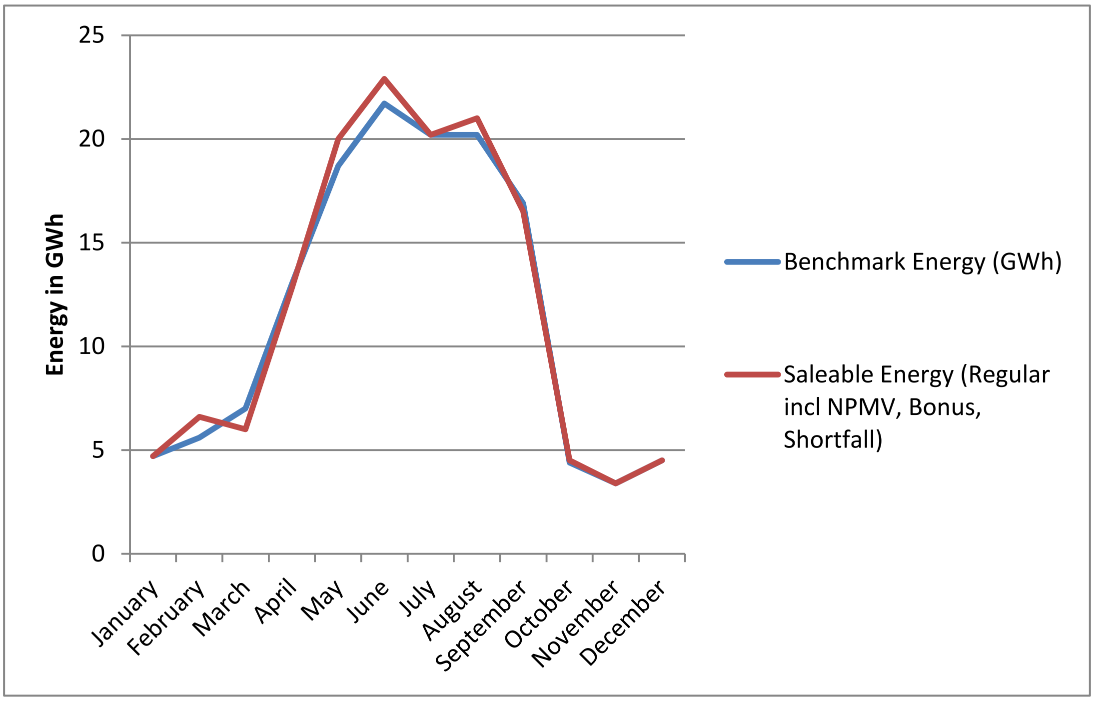
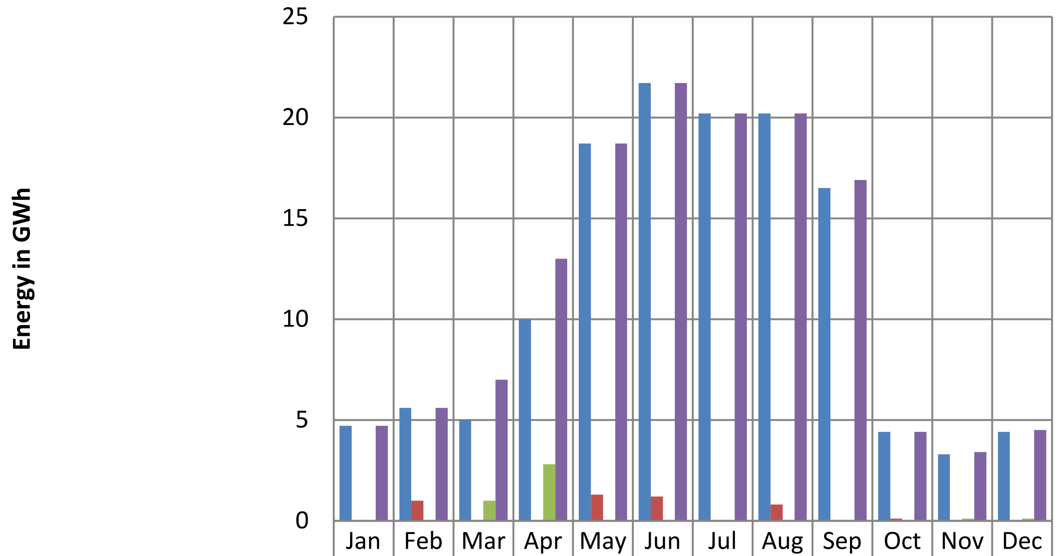


Figure 5.1: Benchmark Energy Vs. Total Energy (Regular including E_{MV}, Bonus, Shortfall)

Graph shown in **Figure 5.2** will elaborate the Regular, Bonus, Shortfall and Benchmark Energy for the whole year.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Regular Energy (GWh)	4.7	5.6	5	10	18.7	21.7	20.2	20.2	16.5	4.4	3.3	4.4
Bonus Energy (GWh)	0	1	0	0	1.3	1.2	0	0.8	0	0.1	0	0
Shortfall Energy (GWh)	0	0	1	2.8	0	0	0	0	0	0	0.1	0.1
Benchmark Energy (GWh)	4.7	5.6	7	13	18.7	21.7	20.2	20.2	16.9	4.4	3.4	4.5

Figure 5.2: Monthly Energy; Regular, Bonus, Shortfall and Benchmark

CHAPTER 6 : CONCLUSION AND RECOMMENDATIONS

6 Conclusion and Recommendation

6.1 Conclusion

The development of wind power around the globe has been phenomenal in recent years. More and more countries are now leaping towards wind energy as a major source of power generation. The development of wind energy, like development of any other new sector in any developing country, faces several difficulties in Pakistan. The country with a huge energy demand that is increasing day by day started its wind energy development program in 2004 with no local experience in this sector. The unreliability of the wind data is found to be the major hurdle in the development of wind power. It is difficult to predict wind speed trends without having long-term reliable wind speed data, which in turn impact the actual power production estimates and calculation of financial return of the projects. A 10% decrease in wind speed will result in approx. 33% decrease in power output of the project and financial returns will be impacted accordingly.

The countries in which the wind industry is growing fast have reliable long term wind data or wind atlas available. Still different approaches are available to overcome the risk associated with wind speed like on-site data gathering on international standards for 02 to 03 years and co-relation with the long term data sets, higher probability factor P(90) or above to calculate output from wind farm, insurance of the wind risk and government incentives like accelerated depreciation in India. The limitations of above solutions will make them good for only specific cases and cannot be applicable to IPP model to attract investment in all the countries. Keeping in view the limitations of the available solutions author proposed the *"Wind Risk"* mechanism, which overcomes the issue of unreliability of the wind data for investors and lenders for fast track development of wind energy in south of Pakistan. The "*Wind Risk*" concept adopted by the Government of Pakistan for the development of wind power projects in Gharo – Keti Bandar Corridor in south of Pakistan can prove to be a role model for other areas in Pakistan where there is no wind data available. Adapting this concept can help fast track development of wind power sector in Pakistan and other parts of the world.

During the course of this research author studied, the masts installed by PMD at Gharo and Nooriabad and found that they did not follow the IEC standard during installation. All the masts installed by PMD have similar issues which are highlighted in the thesis. In addition to that the data logger was locally made and doesn't have any international certification. This makes the whole exercise questionable and data from these masts are termed as unreliable data.

The data sets from these PMD masts were analyzed and Benchmark Wind Speeds have been developed for Gharo and Jhimpir regions. The annual average wind speed for both the regions is calculated as 7.3 m/s at 80 meter height. However, the monthly average wind speeds are different in both the regions. The development of Benchmark wind speed values for different potential areas would lead to rapid development of wind energy in those areas, as the risk of variability of wind would be on the energy purchaser. Wind farm developers can make their financial models considering the annual energy production (AEP) on benchmark wind speed values. This approach shall minimize the financial risks involved in the project that in turn convinced the lenders to invest in wind power projects in those areas.

Data acquisition ratio of both mast found to be more than 90%. It gives confidence that measurement made on the mast are representative.

Wind rose is created using both masts. Comparing the (02) met masts, it is observed that directional data of both masts is symmetric and predominate wind direction is 225 degree (South West Direction). Therefore, common micrositing can serve with both data sets.

Data results from the two met mast shows that data obtained from Zorlu mast shows more consistency than Nooriabad. Major reason of more irregularity in Nooriabad mast is that installation of the measuring anemometer is at low height. Due to this fact Benchmark wind speeds has been established based on 50 m data.

Diurnal variability of Zorlu mast shows that thermal stability in the region is at very low side. It is the reason that sensors at high surface level show more wind speed variation is the daytime. However, Nooriabad mast did not predicted these variations as measurement sensor was install at lower height.

Annual energy is calculated using data of two (02) met masts. Data obtained from two mast is processed in WAsP. It is observed that difference in capacity factor between two masts results is less than 04%. Major reason of this difference is due to comparative quality of mast installation.

A non project missed volume (E_{MVy}) protocol has also been developed as part of the overall *"Wind Risk"* mechanism to immune the investors from the unavailability of the grid when they are available to deliver the energy because of the weak grid network in south of Pakistan. Formulae have been developed as part of the PhD research to calculate the potential power to be delivered to the grid when the grid was unavailable and accordingly the payments shall be made to the project.

Translation of the "*Wind Risk*" has also been made into the contractual agreements where payment mechanism is laid down with formulae developed by the author that would govern the energy payments based on "*Wind Risk*" coverage. It is concluded that the mechanism proposed in this thesis for the use of "*Wind Risk*" concept is ideal for fast track and sustainable development of wind energy in countries / areas with wind potential not supported by historical and International Standard wind data.

6.2 Recommendations and Way Forward

1. Met Masts installed by PMD [52] in south of Pakistan at Gharo Keti-bandar wind corridor needs to be up-graded as per the IEC standards in order to harness the reliable wind data. Detailed recommendations are given in this regard in **Chapter 4** of this thesis by the author. A parallel anemometry system may be installed along with the existing anemometry systems installed at PMD met masts to record the perturbations made by the short booms and the tower shadow effects. By the correlation of two data sets of same level and the recorded perturbations at one mast will definitely lead to develop the reliable long term historical wind data. The author recommends a PhD level research in this connection.
2. Identification of new areas for the development of wind energy in Pakistan is the need of the hour. Wind Resource Map of Pakistan developed by NREL [26] showed potential areas in other provinces in Pakistan other than Sindh province. Long term met data and/or onsite wind data for those areas are not available. Universities can help Government of Pakistan by initiating the research in those areas and develop benchmarks so that wind energy can be developed in those areas as well. Two more PhD level research projects are recommended to explore potential and develop benchmark wind speeds in wind power potential areas in Kheber Pakhtoon Khwa and Punjab. Onsite international standard masts can be installed in some potential areas and correlation with NREL map may also be established and studied.
3. Lenders concerns on "*Wind Risk*" approach should be studied in more detail. This concept is new and definitely more wind farm than the mechanisms used in the other parts of the world. It is recommended that a PhD level research may be initiated to see if lenders are comfortable to go ahead with this concept for the fast track development of wind energy in areas with less or unreliable wind data. Author believes that this approach can also help other developing countries to kick-start the wind energy projects in regions where wind is available but not the historical wind data.

Author wish and pray that this research will spur a new beginning to find the innovative and practical solutions to overcome the issue of the unreliable data; which is a key issue impeding the development of wind energy in developing and under developed countries like Pakistan.

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ANNEXURE-I

EXAMPLES

Example No. 1:

E_{MV} Calculation during the First Month after Commissioning

The Wind farm Monthly Power Curve Energy (CMPCE) table provided by the wind farm developers for the month under consideration is as follows;

Table A-I-1: Monthly Power Curve Energy

S #	Wind Speed (m/s)	E_{PC} (GWh/month)	S #	Wind Speed (m/s)	E_{PC} (GWh/month)
1	3.0	0.3	27	5.6	5.0
2	3.1	0.4	28	5.7	5.4
3	3.2	0.4	29	5.8	5.7
4	3.3	0.5	30	5.9	6.0
5	3.4	0.5	31	6.0	6.3
6	3.5	0.6	32	6.1	6.7
7	3.6	0.7	33	6.2	7.0
8	3.7	0.9	34	6.3	7.3
9	3.8	1.0	35	6.4	7.7
10	3.9	1.1	36	6.5	8.1
11	4.0	1.3	37	6.6	8.4
12	4.1	1.5	38	6.7	8.8
13	4.2	1.6	39	6.8	9.2
14	4.3	1.8	40	6.9	9.4
15	4.4	2.0	41	7	9.8
16	4.5	2.2	42	7.1	10.2
17	4.6	2.4	43	7.2	10.5
18	4.7	2.7	44	7.3	10.9
19	4.8	2.8	45	7.4	11.3
20	4.9	3.1	46	7.5	11.6
21	5.0	3.3	47	7.6	12.0
22	5.1	3.7	48	7.7	12.4
23	5.2	3.9	49	7.8	12.7
24	5.3	4.2	50	7.9	13.1
25	5.4	4.5	51	8	13.5
26	5.5	4.8			

Summary of Missed Volume Events during the Month:

1. First Missed Volume Event of the Month

Day 10, from 1730-2100 hrs,

t_{MVE} = 210 minutes, NT_{MVE}=33, T_{WTG}=33,

Ten (10) minute mean of actual wind speed measurements recorded during the period of Missed Volume Events by the Anemometry System

Table A-I-2: Ten (10) Minute Mean of Actual Wind Speed Measurement

S #	Time	10 minute mean of actual wind speed measurements
1	1740	6
2	1750	6
3	1800	6.2
4	1810	6.1
5	1820	5.7
6	1830	5.9
7	1840	5.9
8	1850	5.9
9	1900	6
10	1910	6
11	1920	6.1
12	1930	6.1
13	1940	6.1
14	1950	6.2
15	2000	6.2
16	2010	6.2
17	2020	6.3
18	2030	6.3
19	2040	6.2
20	2050	6.1
21	2100	6
Total		**127.5**

2. Second Missed Volume Event of the Month

Day 30, from 1300- 1400 hrs

t_{MVE} = 60 minutes, NT_{MVE}=30, T_{WTG}=33

Ten (10) minute mean of actual wind speed measurements recorded during the period of Missed Volume Event by the Anemometry System

Table A-I-3: Ten (10) Minute Mean of Actual Wind Speed Measurement

S #	Time	10 minute mean of actual wind speed measurements
1	1310	5.2
2	1320	5.2
3	1330	5.3
4	1340	5.4
5	1350	5.4
6	1400	5.5
Total		**32**

Calculation of Non Project Missed Volume for the Month

a) **E_{PC}**

Average MVE Wind Speed = $\sum x / n$

where

x = 10 minute mean of actual wind speed measurements during the Missed Volume Event during the given Month

n = number of 10 minute means during the Missed Volume Event during the given Month (number of observations)

Average MVE Wind Speed = (127.5 + 32) / (21 + 6) = 5.91 m/s

E_{PC} = **6 GWh**

b) **d_{MVE}**

$d_{MVE, avg}$ =

= (210 * 33 / 33) + (60 * 30 / 33)

= **264.54 minutes**

c) **t_{start}**

t_{start} = (1*33)+(1*30)

= 63 **minutes**

d) **T_m**

T_m = Number of minutes in a given Month

= (30 * 24 * 60) = **43,200 minutes**

e) **Av.**

$E_{D,p}$ = Net Delivered Energy before first MVE = 1.8GWh

E_{MVE} = Nil

$E_{PC,p}$ = (6.8 * 12,700) /(30 * 24 * 60) = 1.9991 GWh

where

Time lapsed before the 1st MVE = 8 days 19 hrs 40 min = 12,700 minutes

Average wind speed before 1st MVE = 6.2 m/s

E_{PC} @ 6.2 m/s = 6.8 GWh

Now

$Av = (E_{D,p} + E_{MVE,p}) / E_{PC,p}$

$Av = 1.8 / 1.9991 =$ **0.900** (i.e. 90%)

$\mathbf{E_{MVE} = E_{PC} * [(d_{MVE, avg} + t_{start}) / T_m] * Av}$

$= (6 \text{ GWh} * (264.54 + 63) / 43{,}200) * 0.90$

$\mathbf{E_{MVE} =}$ **0.04096 GWh**

<u>Example 2</u>:

E_{MV} Calculation after the First 12 Month of Commissioning (all data same as the first example except for the Month, which in this example is not the first month after Commissioning)

The E_{PC} table for the month under consideration is as follows;

Table A-I-4: E_{pc} for the Month under Consideration

S #	Wind Speed (m/s)	E_{PC} (GWh/month)	S #	Wind Speed (m/s)	PC (GWh/month)
1	3.0	0.3	27	5.6	5.0
2	3.1	0.4	28	5.7	5.4
3	3.2	0.4	29	5.8	5.7
4	3.3	0.5	30	5.9	6.0
5	3.4	0.5	31	6.0	6.3
6	3.5	0.6	32	6.1	6.7
7	3.6	0.7	33	6.2	7.0
8	3.7	0.9	34	6.3	7.3
9	3.8	1.0	35	6.4	7.7
10	3.9	1.1	36	6.5	8.1
11	4.0	1.3	37	6.6	8.4
12	4.1	1.5	38	6.7	8.8
13	4.2	1.6	39	6.8	9.2
14	4.3	1.8	40	6.9	9.4
15	4.4	2.0	41	7	9.8
16	4.5	2.2	42	7.1	10.2
17	4.6	2.4	43	7.2	10.5
18	4.7	2.7	44	7.3	10.9
19	4.8	2.8	45	7.4	11.3
20	4.9	3.1	46	7.5	11.6
21	5.0	3.3	47	7.6	12.0
22	5.1	3.7	48	7.7	12.4
23	5.2	3.9	49	7.8	12.7
24	5.3	4.2	50	7.9	13.1
25	5.4	4.5	51	8	13.5
26	5.5	4.8			

Summary of Missed Volume Events during the Month:

1. First Missed Volume Event of the Month

Day 10, from 1430-1800 hrs,

t_{MVE} = 210 minutes, NT_{MVE}=33, T_{WTG}=33,

Ten (10) minute mean of actual wind speed measurements recorded during the period of Missed Volume Event by the Anemometry System

Table A-I-5: Ten (10) Minute Mean of Actual Wind Speed Measurements

S #	Time	10 minute mean of actual wind speed measurements
1	1740	6
2	1750	6
3	1800	6.2
4	1810	6.1
5	1820	5.7
6	1830	5.9
7	1840	5.9
8	1850	5.9
9	1900	6
10	1910	6
11	1920	6.1
12	1930	6.1
13	1940	6.1
14	1950	6.2
15	2000	6.2
16	2010	6.2
17	2020	6.3
18	2030	6.3
19	2040	6.2
20	2050	6.1
21	2100	6
Total		**127.5**

2. Second Missed Volume Event of the Month

Day 30, from 1800- 1900 hrs

t_{MVE} = 60 minutes, NT_{MVE}=30, T_{WTG}=33

Ten (10) minute mean of actual wind speed measurements recorded during the period of Missed Volume Event by the Anemometry System

Table A-I-6: Ten (10) Minute Mean of Actual Wind Speed Measurements

S #	Time	10 minute mean of actual wind speed measurements
1	1310	5.2
2	1320	5.2
3	1330	5.3
4	1340	5.4
5	1350	5.4
6	1400	5.5
Total		**32**

Calculation of Energy due to Missed Volume for the Month

a) E_{PC}

Average MVE Wind Speed = $\sum x / n$

where

x = 10 minute mean of actual wind speed measurements during the Missed Volume Event during the given Month

n = number of 10 minute means during the Missed Volume Events during the given Month (number of observations)

Average MVE Wind Speed = (127.5 + 32) / (21 + 6) = 5.91 m/s

E_{PC} = **6 GWh**

b) $\mathbf{d_{MVE,\,avg}}$

$\mathbf{d_{MVE,\,avg}}$ =

= (210 * 33 / 33) + (60 * 30 / 33)

= **264.54 minutes**

c) $\mathbf{t_{start}}$

$\mathbf{t_{start}}$ = 63 minutes

d) $\mathbf{T_m}$

T_m = Number of minutes in a given Month

= (30 * 24 * 60) = **43,200 minutes**

e) **Av**

(All data for the previous 12 calendar months to the month for which E_{MV} is being calculated)

$E_{D,\,p}$ = 120 GWh

$E_{MV\ p}$ = 10 GWh

$E_{PC,p}$ = 135 GWh

Now

Av = $(E_{Dp} + E_{MV,p}) / E_{PC,p}$

Av = (120 + 10) / 135 = **0.963** (i.e. 96.3%)

$\mathbf{E_{MVE}}$ **=** $\mathbf{E_{PC} * [\ (d_{MVE,\,avg} + t_{start}\ ) / T_m\ ] * Av}$

= (6 GWh * (264.54 + 63) / 43,200) * 0.963

$\mathbf{E_{MV}}$ **= 0.0438 GWh**

ANNEXURE-II

Certificate from AEDB

Government of Pakistan

Certificate of Appreciation

This is presented to ***Mr. Irfan Afzal Mirza***, on his contribution to the wind energy sector of Pakistan.

He initiated and successfully defended the *Wind Risk* concept in Ministry of Water and Power through his presentation.

This concept is accepted to be the part of the Government of Pakistan *Policy for Development of Renewable Energy for Power Generation*.

Air Marshal (Retd.) Shahid Hamid
Chairman
Alternative Energy Development Board
Government of Pakistan

December 2006