# An Investigation on Wind Power Potential of Nalent

**(Three years October2002 to September2005)**

# Executive Summary

Pakistan Meteorological Department conducted a wind potential survey of the coastal areas of Pakistan. The Ministry of Science and Technology gave funding for this project. Under this project wind data was collected at 44 sites along the Sindh & Balochistan Coast.

In this report the analysis based on three years wind data has been presented along with the wind generated electric power at Nalent, Sindh. Wind data with one-minute average speed and direction were collected at 10 meters and 30 meters height and 50 meters values were computed from models.

At 50 meters we have the annual average wind speed of 3.1 m/s. monthly average wind speed never exceed 5 m/s and the highest of 3.8 m/s is observed in July. Seasonal Diurnal Wind Variation indicates that maximum wind speed is available in the early evening around 4pm PST during March to February. Wind frequency distribution shows that during 35% of the time wind speed is 5 m/s or above.

Sometimes simply wind speed averages do not give the true picture of the wind power potential of an area. For this purpose it is common to assign areas to one of the seven wind classes based on “Wind Power Density” of that area. Monthly and Annual Wind Power Density has been computed and added in the report. The Annual Power Density of Nalent is $79.7 W/m^2$. According to International Wind Classification, this power density categorizes the area as a “BELOW MARGINAL” site for wind power generation.

Wind generated Electric Power has as also been computed on hypothetical 600 KW wind turbine and its hourly, monthly and annual values has also been added in this report. The annual power production from a single 600 KW wind turbine comes out to be 0.4 million KWh, which shows the capacity factor of 7% for Nalent. Internationally it is accepted that if any site has a capacity factor of 25% and above than that site is suitable for installation of economically viable wind power farms. As such Nalent and surrounding area can be classified not suitable site for installing big economically viable wind farms.

# 1. Introduction:

Wind energy is the fastest growing renewable energy source today. A continued interest in wind energy development worldwide has produced steady improvements in technology and performance of wind power plants. New wind power projects have proven that wind energy not only is cost competitive but also offers additional benefits to the economy and the environment.

A steady supply of reasonably strong wind is necessary requirement for utilizing the power in the wind. Development of wind energy depends upon a clear understanding of wind resources. Site location, turbine performance and physical effects of turbulence and energy extraction represent a few of the issues that must be addressed by anyone interested in developing wind energy.

As such any plan to develop wind energy must begin by understanding the wind resource. Where are the best potential wind sites located? How much energy could be extracted from the wind at those sites?

## 1.1 Characteristic of wind:

The global winds are caused by pressure differential across the earth's surface. The amount of solar radiation absorbed at the earth's surface is greater at the equator than at the poles. This variation in incoming heat sets up convective cells in the lowest layer of the atmosphere. In the simplest form air rises at the equator and sinks at the poles. However the rotation of the earth complicates this simple heat transfer. A series of circulations are set up in both northern and southern hemispheres.

The areas of the globe where air is descending are zones of high pressure and where the air is ascending, low-pressure zones are formed. The pressure gradient drives the flow of air from high to low pressure, thus causing the wind. The wind is then acted on the corriolis force due to the earth's rotation. The resultant wind is turned easterly or westerly. On a smaller scale, wind is created because of temperature difference between land and sea and mountains and valleys. The local topographical features and roughness of the terrain also cause air movements.

# 2.0 Wind Mapping Project of Pakistan Meteorological Department:

As any plan to develop wind energy must begin by understanding the wind resources. Where are the best potential wind sites located? How much energy could be extracted from the wind at those sites? Will the wind turbine performance be affected by the turbulence or other wind resource characteristics?

To answer these questions and to provide wind resource database for the different potential parts of the country, Pakistan Meteorological Department prepared a phased programme. Government of Pakistan, Ministry of Science and Technology provided the necessary funding for undertaking the Phase I. First phase covers the coastal areas of Sindh and Balochistan Provinces.

## 2.1 Study Area:

The project area for the wind mapping is 1100 kilometers along Sindh and Balochistan coast spreading over latitude 25°N approximately and up to 100 kilometers deep northward over land from the coast.

Forty-four stations for collecting wind data have been installed to study the wind regime as shown in figure-1.

The list of stations located along Sindh and Balochistan coast is given below.

Aghore, Basol, Bella, Gaddani, Gawadar, Hoshab, Hub Chowki, Jiwani, Liari, Makola, Managi, Mand, Nasirabad, Nalent, Ormara, Othal, Pasni, Phore, Pishukhan, Ramra, Tump, Turbat, Winder, Badin, Baghan, Chuhar Jamali, DHA Karachi, Gharo, Golarchi, HawksBay, Hyderabad, Jamshoro, Jati, Kadhan, Karachi, Kati Bandar, Matli, Mirpur Sakro, Nooriabad, Sajawal, Shah Bandar, Talhar, Thanu Bula Khan, Thatta.

## 2.2 Data source:

To undertake this study 30-meter high towers are erected at the locations mentioned above. On each of these high towers two wind speed anemometers are installed at the height of 10 meters and 30 meters, respectively; wind vane for recording wind direction is installed at 30 meters height. Temperature sensors are also installed at 10 meters height. Automatic data loggers developed locally have been installed to record data at each site. These data loggers are recording, one-minute average wind speed at each levels, One-minute average wind direction at 30 meters height, five-minute average temperature and 10-minute average minimum and maximum wind speed at each levels. While selecting the above-mentioned locations for wind monitoring; the main objective was to identify potentially windy areas that also possess other desirable qualities of wind energy developed site. Further following guidelines as far as possible were also kept in mind while choosing an exact location for monitoring towers.

- Towers are placed as for as possible away from the local obstruction to the wind
- Selected location should be representative of the majority of the site.

Since siting a tower near obstructions such as trees or building can adversely affect the analysis of the site's wind characteristics such as magnitude of wind resource, wind shear and turbulence levels the tower in most cases are placed as for as possible away from local obstructions to the wind. But where this rule could not be followed, the tower was placed at horizontal distance of 10 times the height of the obstruction in the prevailing wind direction as required internationally. The following parameters have been recorded during the study.

i. Wind speed one minute average at 10 & 30 meters
ii. Maximum wind speeds during 10 minutes at 10 & 30 meters
iii. Minimum wind speeds during 10 minutes at 10 & 30 meters
iv. Wind direction One minutes average at 30 meters
v. Temperature 5 minutes average in °C at 10 meters

Every month a team of observers and Maintenance Engineers visits these sites to inspect the instruments and to download the data on a laptop. Finally, the data is compiled and analyzed at Renewable Energy Research Cell established at Meteorological Complex, Karachi.

## 3.0 Methodology; Analysis & Discussion:

### 3.1 Wind speed variation with height:

Wind speed tends to increase with height in most locations, a phenomenon known as wind shear. The degree of wind shear depends mainly upon on two factors, atmospheric mixing and the roughness of the terrain.

Atmospheric mixing typically follows a daily cycle driven by solar heating. At the hub height of a wind turbine, this cycle often causes wind speeds to increase in the daytime and decrease at night. However, the range of variation between night and day typically diminishes as hub height increases. At a height of approximately 50 meters, it weakens or may even disappear in some cases.

Terrain roughness also affects wind shear by determining how much the wind is slowed near the ground. In areas with a high degree of roughness, such as forests or cities, near-surface wind speeds tend to be low and wind shear high, whereas the converse is true in areas of low roughness such as flat, open fields. Wind shear may be greatly reduced or eliminated where there is an abrupt change in terrain height such as a sea cliff or mountain ridge.

To save money wind measurements sometimes are taken at a lower height than the wind turbine tower. In that case, it is essential to measure wind shear at different times of day in different seasons to accurately predict the performance of a wind power plant. The shear can be measured by monitoring wind speeds at two or three heights on a tower. Since wind turbines produce much more power in stronger winds, wind turbine designers try to put turbines on the tallest possible towers. At some point, however, the increased cost of towers outweighs the benefits. With current wind turbine technology, the optimum tower height for large wind machines appears to be approximately 40 to 50 meters.

For saving money in this survey also the wind has been recorded at 10 & 30 meters and for calculating the wind speed at 50 meters the following two methods has been used in this study.

#### 3.1.1 *Log Law:*

The turbulent mixing in the atmosphere may be considered in a similar way to molecular mixing (this is called k theory). Assuming the mixing is dominated by mechanical mixing due to shear forces a relationship of wind speed with height is derived.

$$u = \frac{u_*}{k} \ln\left(\frac{z - D}{z_o}\right)$$

Where

$u_*$ is the friction notify

**k** is the von Karman constant

$\mathbf{Z_0}$ is the roughness length

**D** is the displacement height

The von Karman constant is generally taken as 0.4. The roughness length $Z_o$ is related to the vegetation cover of the area. The values of roughness length are given in Table-1. The displacement height D is the height above the roughness elements where the flow is free. For most vegetation it is small and is generally treated as zero. For large roughness elements like trees and building in towns it is not negligible and is the order of the average height of the elements. The **log law** may only be used for heights above D. Turbines are rarely sited in forests or towns, so D is usually taken as zero.

The wind speed at any height z can then be computed provided that the wind speed at a height $Z_R$ is known. Thus:

$$\frac{u}{u_R} = \frac{\ln\left( z / z_o \right)}{\ln\left( z_R / z_o \right)}$$

Where

$U_R$ is the wind speed at reference height $Z_R$

The reference height is usually 10m or 30m as this is the height at which mean wind data is generally collected.

### 3.1.2 ***Power Law:***

Engineers often prefer to use a Power Law to describe the increase in wind speed with height, as it is easier to evaluate.

$$\frac{u}{u_R} = \left( \frac{z - D}{z_R} \right)^{\alpha}$$

Where:

$\alpha$ is the power law exponent

$u_R$ is the wind speed at reference height $z_R$

The power law exponent typically varies between 0.1 and 0.32 depending upon the landscape type. A value of 1/7 is often quoted as a reasonable value for the power law exponent in countryside. The exponent can be calculated from the roughness length.

$$\alpha = \frac{\ln\left( \ln\left( z / z_o \right) \Big/ \ln\left( z_R / z_o \right) \right)}{\ln\left( z / z_R \right)} \approx \frac{1}{\ln\sqrt{\dfrac{z \cdot z_R}{z_o}}}$$

Where:

Z is the measurement height

$Z_R$ is the reference height

$Z_0$ is the roughness length

The power law exponent therefore varies with the interval between the two measurement heights. The power law should be carefully employed since it is not a physical representation of the surface layer and does not describe the flow nearest to the ground very well. Both the log law and the power law are simplified expressions of the wind profile. They are valid in flat homogeneous terrain. So they do not include the effects of topography, obstacles or changes in roughness or stability.

**Table 1:** Typical values of surface roughness length $Z_O$ and power law exponent $\alpha$ for various types of terrain

| **Type of terrain** | **$Z_0$** | **A** |
|---|---|---|
| Mud Flats, Ice | $10^{-5}$ to $3x\ 10^{-5}$ | |
| Calm Sea | $2x10^{-4}$ to $3x10^{-4}$ | |
| Sand | $2x10^{-4}$ to $10^{-3}$ | 0.01 |
| Mown Grass | 0.001 to 0.01 | |
| Low Grass | 0.01 to 0.04 | 0.13 |
| Fallow Field | 0.02 to 0.03 | |
| High Grass | 0.04 to 0.1 | 0.19 |
| Forest and Woodland | 0.1 to 1 | |
| Built up area, Suburb | 1 to 2 | 0.32 |
| City | 1 to 4 | |

## 3.2 **Average Wind Speed:**

By using above mentioned methods the wind speed at 50 meters has been computed and monthly average of these wind speed at 50 meters height have been given in Fig-2 in graphical as well as tabular form.

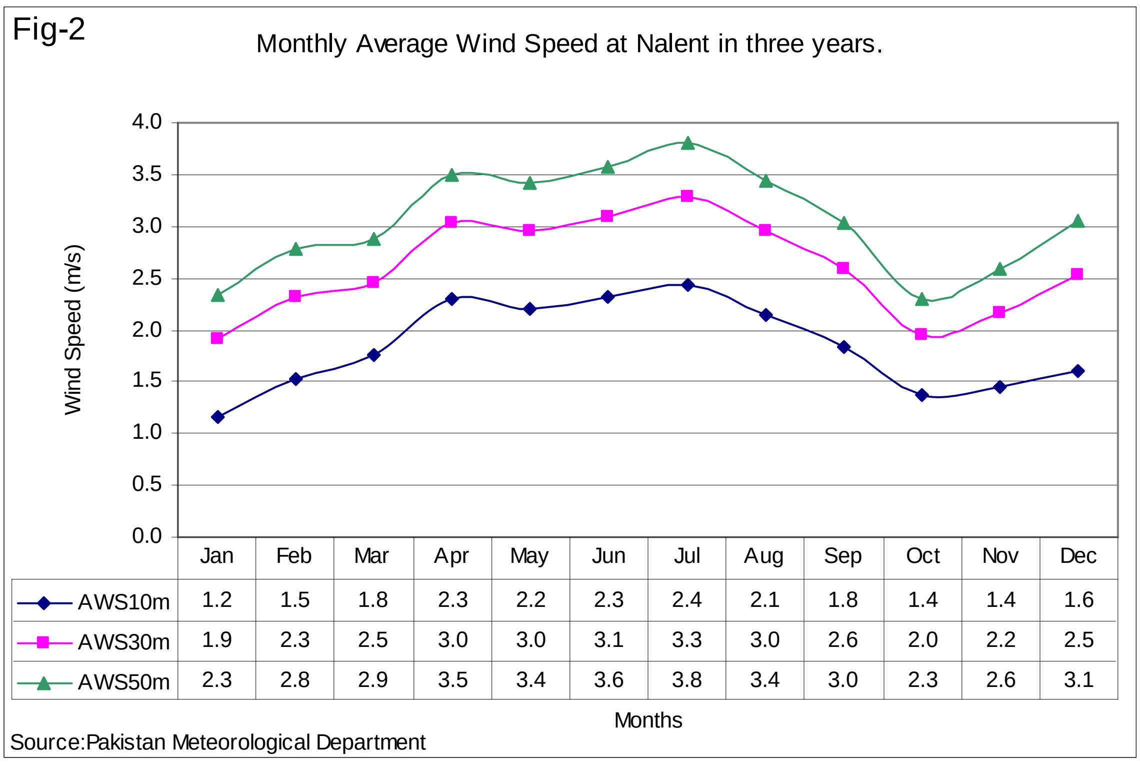


Fig-2 shows monthly average wind speed at height of 10 meters, 30 meters and 50 meters. At 10 meters height, we have the average wind speed of less than 5 m/s during of the period, whereas maximum average wind speed of 2.4 m/s is recorded in July. At 30 meters height, we have the average wind speed of less than 5 m/s during the period, whereas maximum average wind speed of 3.3 m/s is recorded in July.

At 50 meters height, we have average wind speed of less than 4.5m/s during of the period; the highest wind that we get is 3.8 m/s in the month of July.

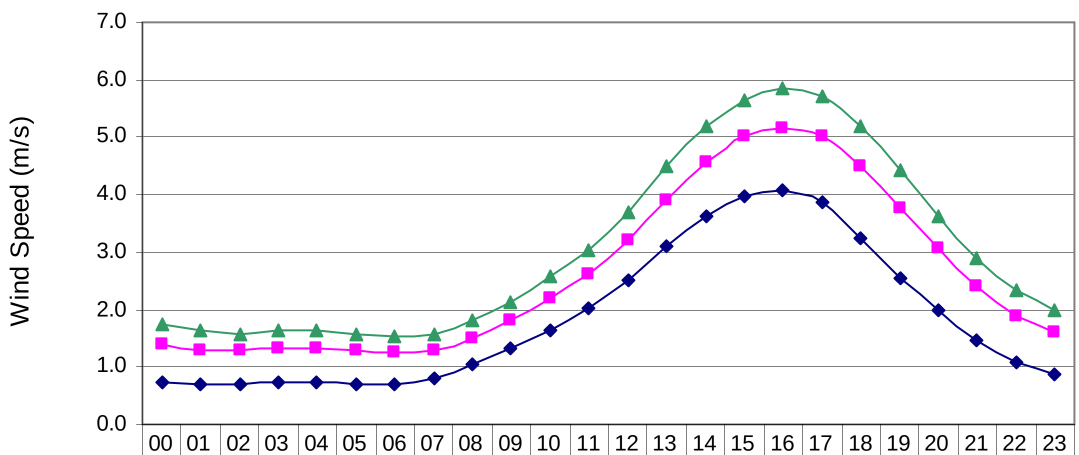
### 3.3 Diurnal Wind speed Variation:

Fig-3 shows the annual diurnal wind speed variations at Nalent. At 30 meters height the wind varies from minimum 1.2 m/s to maximum 5.2 m/s and at 50 meters height it varies from minimum 1.5 m/s to maximum 5.8 m/s.

Figures 4 to 7 shows seasonal diurnal variation of wind speed. Figure-4 shows that during March to May period, in three years at 50 meters height the maximum wind speed reaches to 6.7m/s and Figure-5 shows that it reaches to 6.8 m/s during June to August period in three years.

Fig-3

Annual Diurnal Variation of Wind Speed at Nalent in three years




| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AWS10m | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.8 | 1.0 | 1.3 | 1.6 | 2.0 | 2.5 | 3.1 | 3.6 | 4.0 | 4.1 | 3.9 | 3.3 | 2.5 | 2.0 | 1.5 | 1.1 | 0.9 |
| AWS30m | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.2 | 1.3 | 1.5 | 1.8 | 2.2 | 2.6 | 3.2 | 3.9 | 4.6 | 5.0 | 5.2 | 5.0 | 4.5 | 3.7 | 3.1 | 2.4 | 1.9 | 1.6 |
| AWS50m | 1.7 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.5 | 1.6 | 1.8 | 2.1 | 2.6 | 3.0 | 3.7 | 4.5 | 5.2 | 5.7 | 5.8 | 5.7 | 5.2 | 4.4 | 3.6 | 2.9 | 2.3 | 2.0 |

Pakistan Standard Time (PST)

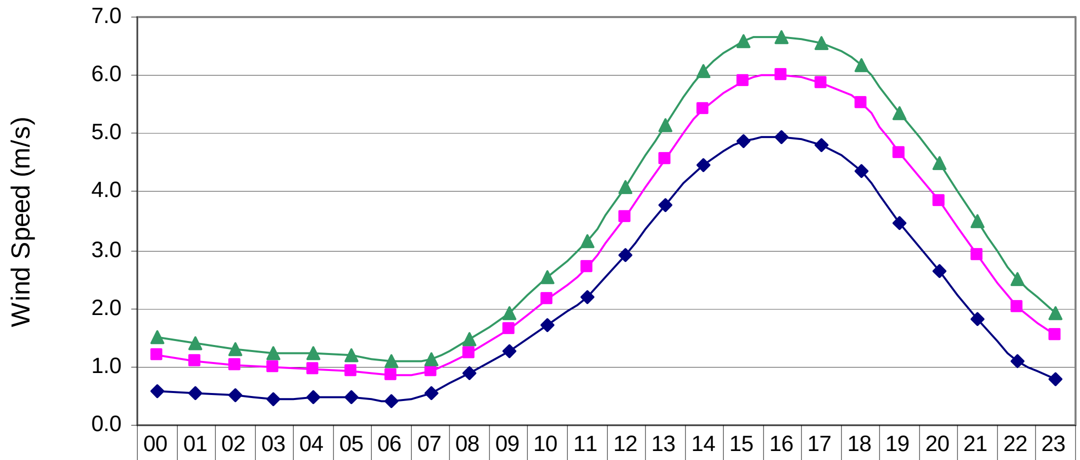
Source:Pakistan Meteorological Department

| Table for Fig-2 | Monthly Average Wind Speed (m/s) at Nalent | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nalent Oct2002 to Sep2003 | | | Nalent Oct2003 to Sep2004 | | | Nalent Oct2004 to Aug2005 | | |
| Months | AWS10m | AWS30m | AWS50m | AWS10m | AWS30m | AWS50m | AWS10m | AWS30m | AWS50m |
| Jan | 1.1 | 1.8 | 2.1 | 1.1 | 1.8 | 2.2 | 1.3 | 2.2 | 2.7 |
| Feb | 1.6 | 2.4 | 2.9 | 1.4 | 2.0 | 2.4 | 1.6 | 2.6 | 3.1 |
| Mar | 1.8 | 2.5 | 2.9 | 1.8 | 2.4 | 2.7 | 1.7 | 2.5 | 3.0 |
| Apr | 2.0 | 2.7 | 3.2 | 2.7 | 3.5 | 3.9 | 2.1 | 2.9 | 3.4 |
| May | 2.3 | 3.2 | 3.7 | 2.2 | 2.8 | 3.2 | 2.1 | 2.9 | 3.4 |
| Jun | 2.3 | 3.1 | 3.6 | 2.6 | 3.2 | 3.7 | 2.1 | 2.9 | 3.4 |
| Jul | 2.5 | 3.3 | 3.8 | 2.5 | 3.3 | 3.7 | 2.4 | 3.3 | 3.8 |
| Aug | 2.1 | 2.8 | 3.3 | 2.4 | 3.2 | 3.7 | 1.9 | 2.8 | 3.3 |
| Sep | 1.9 | 2.5 | 3.0 | 1.8 | 2.6 | 3.1 | | | |
| Oct | 1.7 | 2.4 | 2.8 | 1.2 | 1.6 | 2.0 | 1.2 | 1.8 | 2.2 |
| Nov | 1.4 | 2.1 | 2.5 | 2.1 | 3.0 | 3.6 | 0.9 | 1.4 | 1.7 |
| Dec | 1.8 | 2.8 | 3.3 | 1.7 | 2.5 | 3.0 | 1.4 | 2.3 | 2.9 |
| Annual | 1.9 | 2.6 | 3.1 | 1.9 | 2.7 | 3.1 | 1.7 | 2.5 | 3.0 |

| Table for Fig-3 | Annual Diurnal Variation of Wind Speed (m/s) at Nalent | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nalent Oct2002 to Sep2003 | | | Nalent Oct2003 to Sep2004 | | | Nalent Oct2004 to Aug2005 | | |
| PST | AWS10m | AWS30m | AWS50m | AWS10m | AWS30m | AWS50m | AWS10m | AWS30m | AWS50m |
| 00 | 0.7 | 1.3 | 1.7 | 0.8 | 1.4 | 1.7 | 0.7 | 1.4 | 1.7 |
| 01 | 0.6 | 1.2 | 1.6 | 0.8 | 1.4 | 1.7 | 0.6 | 1.3 | 1.6 |
| 02 | 0.7 | 1.3 | 1.6 | 0.8 | 1.4 | 1.7 | 0.6 | 1.2 | 1.5 |
| 03 | 0.8 | 1.4 | 1.7 | 0.8 | 1.3 | 1.7 | 0.6 | 1.2 | 1.5 |
| 04 | 0.9 | 1.5 | 1.8 | 0.7 | 1.3 | 1.6 | 0.6 | 1.1 | 1.4 |
| 05 | 0.9 | 1.4 | 1.8 | 0.7 | 1.3 | 1.6 | 0.6 | 1.1 | 1.4 |
| 06 | 0.8 | 1.4 | 1.7 | 0.7 | 1.3 | 1.6 | 0.6 | 1.1 | 1.4 |
| 07 | 0.9 | 1.4 | 1.7 | 0.9 | 1.4 | 1.6 | 0.7 | 1.1 | 1.4 |
| 08 | 1.1 | 1.6 | 1.9 | 1.2 | 1.6 | 1.9 | 0.9 | 1.3 | 1.6 |
| 09 | 1.3 | 1.8 | 2.1 | 1.5 | 2.0 | 2.3 | 1.2 | 1.7 | 2.0 |
| 10 | 1.6 | 2.2 | 2.6 | 1.8 | 2.3 | 2.7 | 1.5 | 2.1 | 2.5 |
| 11 | 2.0 | 2.6 | 3.1 | 2.1 | 2.7 | 3.1 | 1.9 | 2.5 | 2.9 |
| 12 | 2.6 | 3.2 | 3.8 | 2.6 | 3.2 | 3.7 | 2.3 | 3.1 | 3.6 |
| 13 | 3.1 | 3.9 | 4.5 | 3.2 | 3.9 | 4.5 | 2.9 | 3.8 | 4.4 |
| 14 | 3.6 | 4.6 | 5.2 | 3.8 | 4.6 | 5.2 | 3.5 | 4.5 | 5.2 |
| 15 | 3.9 | 4.9 | 5.6 | 4.2 | 5.1 | 5.7 | 3.8 | 5.0 | 5.7 |
| 16 | 4.0 | 5.1 | 5.7 | 4.3 | 5.3 | 5.9 | 3.9 | 5.2 | 5.9 |
| 17 | 3.9 | 5.0 | 5.7 | 4.0 | 5.0 | 5.7 | 3.7 | 5.0 | 5.7 |
| 18 | 3.3 | 4.5 | 5.2 | 3.4 | 4.5 | 5.2 | 3.0 | 4.4 | 5.1 |
| 19 | 2.6 | 3.8 | 4.5 | 2.7 | 3.8 | 4.4 | 2.4 | 3.6 | 4.3 |
| 20 | 2.1 | 3.2 | 3.7 | 2.1 | 3.1 | 3.7 | 1.8 | 2.9 | 3.5 |
| 21 | 1.5 | 2.5 | 3.0 | 1.5 | 2.4 | 2.9 | 1.3 | 2.3 | 2.8 |
| 22 | 1.1 | 1.9 | 2.4 | 1.1 | 1.9 | 2.3 | 1.0 | 1.9 | 2.3 |
| 23 | 0.8 | 1.6 | 2.0 | 0.9 | 1.6 | 2.0 | 0.8 | 1.6 | 2.0 |
| Average | 1.9 | 2.6 | 3.1 | 1.9 | 2.7 | 3.1 | 1.7 | 2.5 | 3.0 |

Fig-4

Diurnal Variation of Wind Speed at Nalent (Mar to May) in three Years



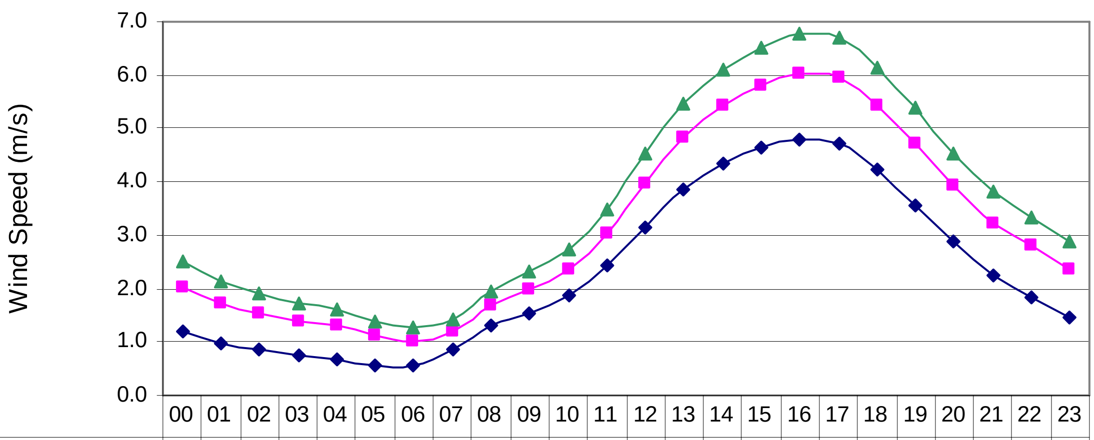

| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AWS10m | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 | 0.5 | 0.9 | 1.3 | 1.7 | 2.2 | 2.9 | 3.8 | 4.4 | 4.9 | 5.0 | 4.8 | 4.4 | 3.5 | 2.7 | 1.8 | 1.1 | 0.8 |
| AWS30m | 1.2 | 1.1 | 1.0 | 1.0 | 1.0 | 0.9 | 0.8 | 0.9 | 1.2 | 1.6 | 2.2 | 2.7 | 3.6 | 4.6 | 5.4 | 5.9 | 6.0 | 5.9 | 5.5 | 4.7 | 3.8 | 2.9 | 2.0 | 1.5 |
| AWS50m | 1.5 | 1.4 | 1.3 | 1.2 | 1.2 | 1.2 | 1.1 | 1.1 | 1.5 | 1.9 | 2.5 | 3.2 | 4.1 | 5.1 | 6.1 | 6.6 | 6.7 | 6.5 | 6.2 | 5.4 | 4.5 | 3.5 | 2.5 | 1.9 |

Pakistan Standard Time (PST)

Source:Pakistan Meteorological Department

Fig-5

Diurnal Variation of Wind Speed at Nalent (Jun to Aug) in three Years

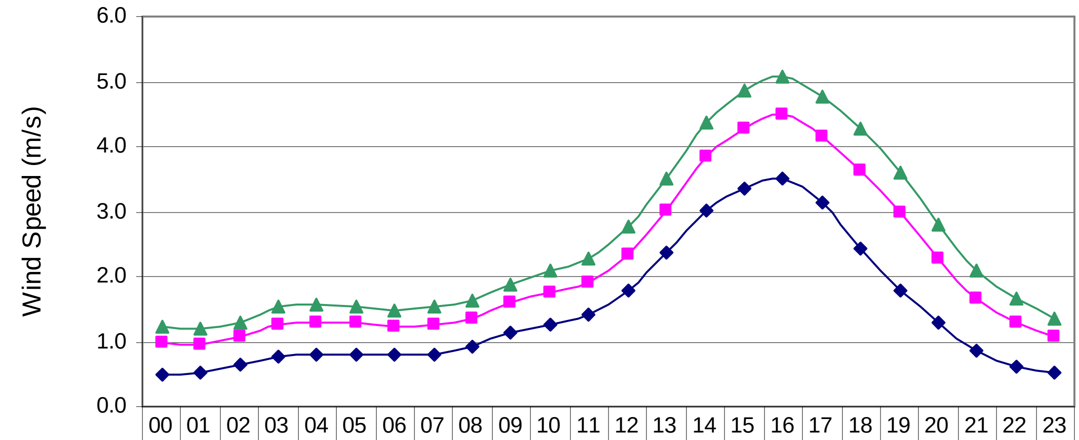



| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AWS10m | 1.2 | 1.0 | 0.8 | 0.8 | 0.7 | 0.6 | 0.5 | 0.8 | 1.3 | 1.5 | 1.9 | 2.4 | 3.2 | 3.8 | 4.4 | 4.7 | 4.8 | 4.7 | 4.2 | 3.6 | 2.9 | 2.2 | 1.8 | 1.5 |
| AWS30m | 2.0 | 1.7 | 1.5 | 1.4 | 1.3 | 1.1 | 1.0 | 1.2 | 1.7 | 2.0 | 2.3 | 3.0 | 4.0 | 4.8 | 5.4 | 5.8 | 6.0 | 5.9 | 5.4 | 4.7 | 3.9 | 3.2 | 2.8 | 2.4 |
| AWS50m | 2.5 | 2.1 | 1.9 | 1.7 | 1.6 | 1.4 | 1.3 | 1.4 | 2.0 | 2.3 | 2.7 | 3.5 | 4.5 | 5.5 | 6.1 | 6.5 | 6.8 | 6.7 | 6.1 | 5.4 | 4.5 | 3.8 | 3.3 | 2.9 |

Pakistan Standard Time (PST)

Source:Pakistan Meteorological Department

Fig-6 Diurnal Variation of Wind Speed at Nalent (Sep to Nov) in three years




| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AWS10m | 0.5 | 0.5 | 0.6 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.9 | 1.1 | 1.3 | 1.4 | 1.8 | 2.4 | 3.0 | 3.4 | 3.5 | 3.1 | 2.4 | 1.8 | 1.3 | 0.9 | 0.6 | 0.5 |
| AWS30m | 1.0 | 1.0 | 1.1 | 1.3 | 1.3 | 1.3 | 1.2 | 1.3 | 1.4 | 1.6 | 1.8 | 1.9 | 2.3 | 3.0 | 3.8 | 4.3 | 4.5 | 4.2 | 3.6 | 3.0 | 2.3 | 1.7 | 1.3 | 1.1 |
| AWS50m | 1.2 | 1.2 | 1.3 | 1.5 | 1.6 | 1.5 | 1.5 | 1.5 | 1.6 | 1.9 | 2.1 | 2.3 | 2.8 | 3.5 | 4.4 | 4.9 | 5.1 | 4.8 | 4.3 | 3.6 | 2.8 | 2.1 | 1.7 | 1.4 |

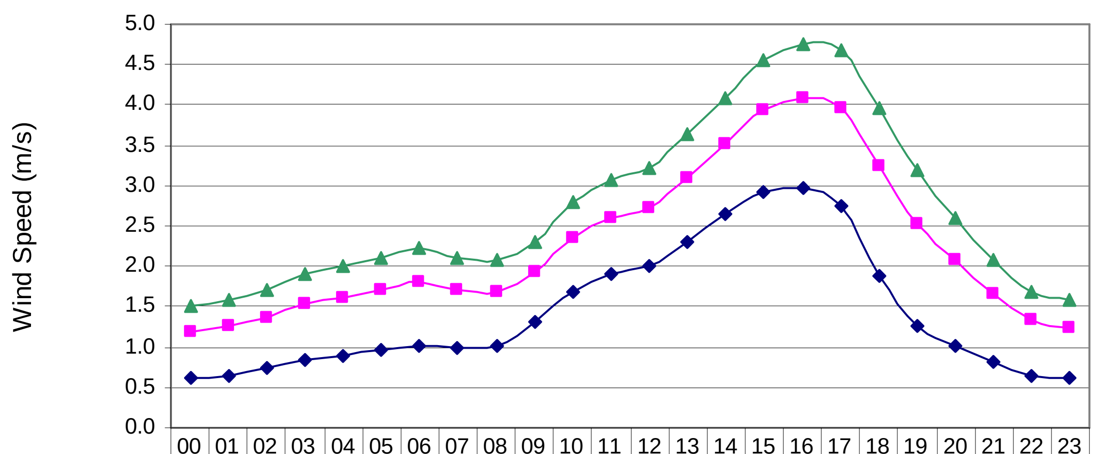
Pakistan Standard time (PST)

Source:Pakistan Meteorological Department

Fig-6 shows the diurnal variation during September to November period in three years and during this period the maximum wind speed is 4.5 m/s at 30 meters height and 5.1 m/s at 50 meters.

Fig-7 shows this variation during the period December to February in three years. Here the maximum wind speed is reach to 4.1 m/s at 30 meters and 4.8 m/s at 50 meters height. This is the period when we experience the relatively low wind speeds in the region.

Fig-7 Diurnal Variation of Wind Speed at Nalent (Dec to Feb) in three Years




| | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AWS10m | 0.6 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | 1.3 | 1.7 | 1.9 | 2.0 | 2.3 | 2.6 | 2.9 | 3.0 | 2.7 | 1.9 | 1.3 | 1.0 | 0.8 | 0.6 | 0.6 |
| AWS30m | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.7 | 1.7 | 1.9 | 2.3 | 2.6 | 2.7 | 3.1 | 3.5 | 3.9 | 4.1 | 4.0 | 3.2 | 2.5 | 2.1 | 1.7 | 1.3 | 1.2 |
| AWS50m | 1.5 | 1.6 | 1.7 | 1.9 | 2.0 | 2.1 | 2.2 | 2.1 | 2.1 | 2.3 | 2.8 | 3.1 | 3.2 | 3.6 | 4.1 | 4.6 | 4.8 | 4.7 | 4.0 | 3.2 | 2.6 | 2.1 | 1.7 | 1.6 |

Pakistan Standard Time (PST)

Source:Pakistan Meteorological Department

3.4 **Wind speed Frequency Distribution:**

Wind speed frequency distribution can simply be obtained by plotting the different wind speeds against their frequencies / relative frequencies. For obtaining frequency distribution the following two procedures are necessary.

3.4.1 ***Binning of Data:***

The sorting of the data into narrow wind speed bands is called binning of the data. In our case a bin width of 1m/sec has been used e.g. a measured wind speed of 3.5 m/sec would be placed in 3<X<=4 m/sec bin. The central value of each bin i.e. 0.5 m/sec, 1.5 m/sec etc has been used in calculations and frequency distribution group.

3.4.2 ***Relative Frequency:***

It is proportional wind speed in each bin. It can be viewed as the estimate of probability of given wind speed in the bin. Relative frequency is defined as

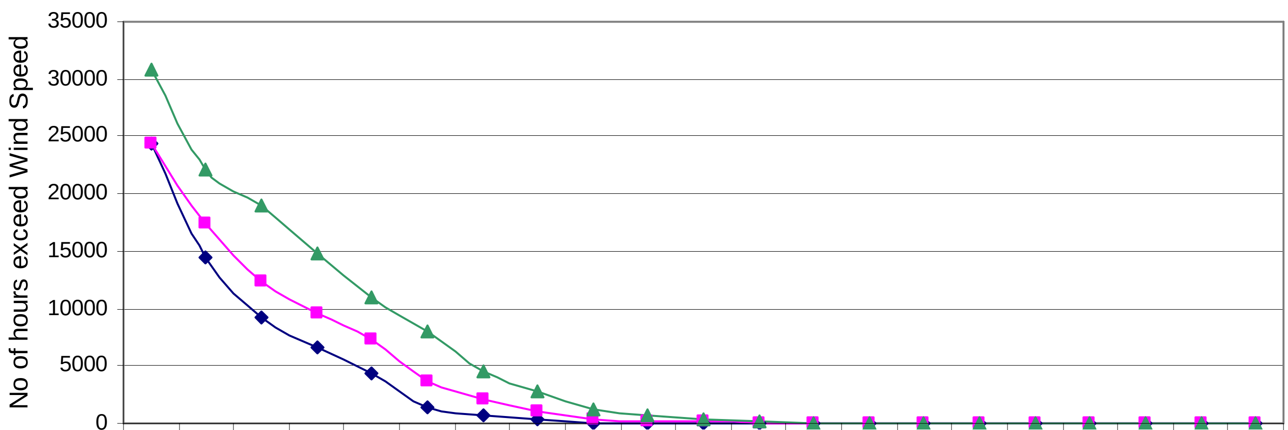
**R .F = probability P (Vi ) = Frequency of given wind speed / Total period**

3.4.3 ***Annual Cumulative Wind Frequency:***

Fig-8 shows the annual cumulative Wind Frequency distribution at three heights 10, 30 and 50 meters. The analysis indicate that at a height of 30 meters, out of 24348 hours in three years during 7295 hours the wind speed is greater than or equal to 5 m/s which generally is enough to generate the electric power. Where as at 50 meters, in three years during 10934 hours the wind speed is greater than or equal to 5m/s.

Fig-8

Comulative Wind Speed Distribution at Nalent in three years




| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CWS10m | 24348 | 14518 | 9162 | 6595 | 4362 | 1449 | 685 | 315 | 81 | 37 | 14 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| CWS30m | 24348 | 17372 | 12388 | 9638 | 7295 | 3640 | 2094 | 1085 | 334 | 195 | 114 | 35 | 17 | 7 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| CWS50m | 30896 | 22190 | 19052 | 14750 | 10934 | 7926 | 4459 | 2795 | 1224 | 628 | 327 | 163 | 76 | 37 | 16 | 7 | 3 | 2 | 1 | 1 | 0 |

Wind Speed (m/s)

Source:Pakistan Meteorological Department

### 3.4.4 ***Wind Frequency Distribution:***

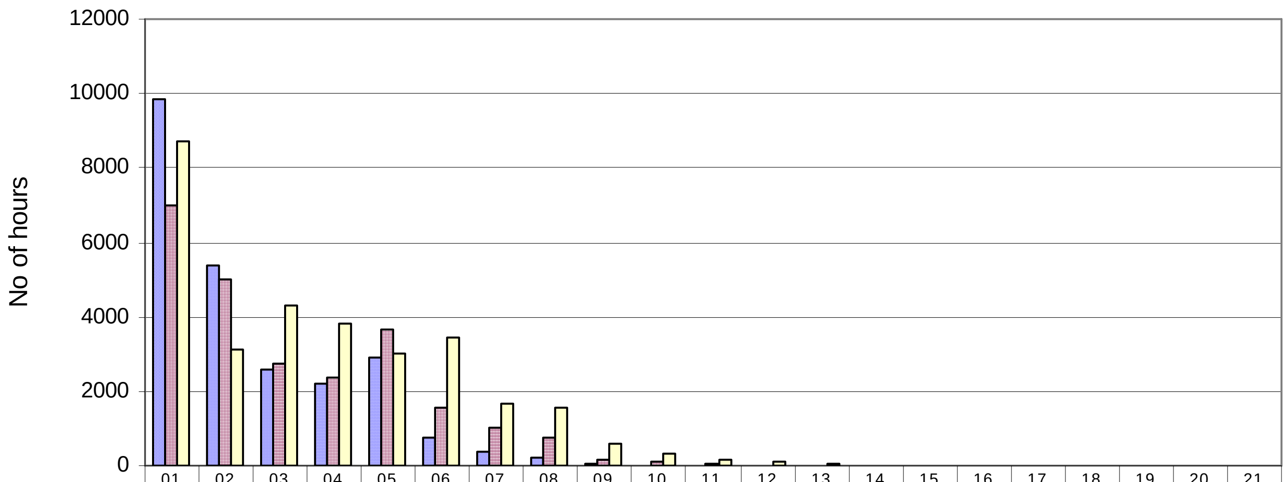
Fig-9 shows the annual frequency distribution. We can see that at 50 meters height, out of 24348 hours in three years, during 3008 hours wind speed is 5 m/s, 3467 hours speed is 6 m/s, 1665 hours speed is 7 m/s, 1571 hours speed is 8 m/s, 596 hours speed is 9 m/s, during 301 hours the wind speed is 10m/s, 164 hours speed is 11 m/s and so on.

Fig-10 gives this frequency distribution in percentage. At 50 meters we find that during 9.9% of time wind is 5m/s, 11.1% of the time 6m/s, 5.2% of the time it is 7m/s and 4.7% of the time it is 8m/s.

Whereas at 30 meters height we get 15.0% of the time wind speed 5m/s, 6.4% of the times 6m/s 4.2% of the time 7m/s and 3.2% of the time 8m/s.

Fig-9

Annual Wind Frequency Distribution at Nalent in three years



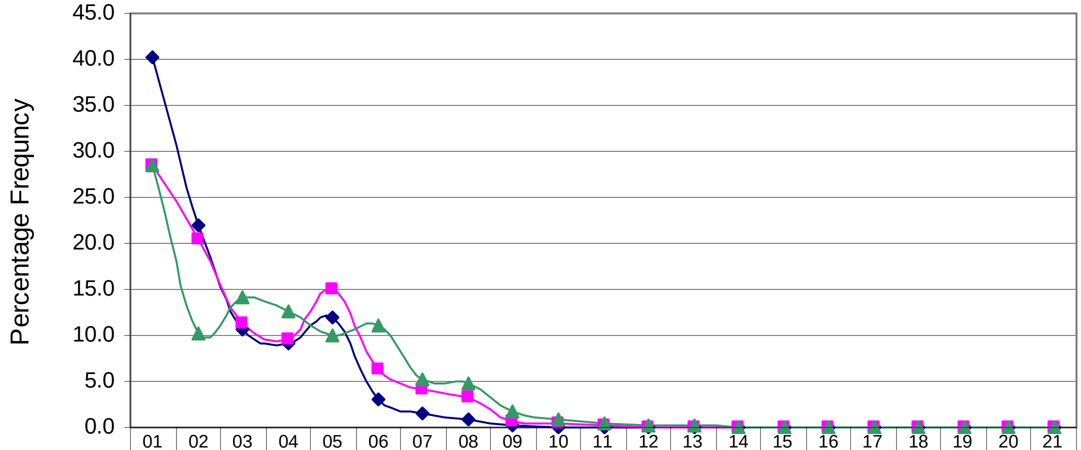

| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WFD10m | 9830 | 5356 | 2567 | 2233 | 2914 | 764 | 369 | 234 | 44 | 23 | 13 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD30m | 6976 | 4984 | 2749 | 2344 | 3655 | 1546 | 1009 | 750 | 140 | 81 | 79 | 18 | 9 | 6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD50m | 8706 | 3138 | 4302 | 3816 | 3008 | 3467 | 1665 | 1571 | 596 | 301 | 164 | 86 | 39 | 21 | 9 | 4 | 1 | 1 | 1 | 0 | 0 |

Wind Speed (m/s)

Source:Pakistan Meteorological Department

Fig-10

Annual Percentage Wind Frequency Distribution at Nalent in three years




| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PFD10m | 40.3 | 22.0 | 10.6 | 9.2 | 12.0 | 3.1 | 1.5 | 0.9 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD30m | 28.6 | 20.4 | 11.3 | 9.6 | 15.0 | 6.4 | 4.2 | 3.2 | 0.6 | 0.3 | 0.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD50m | 28.4 | 10.3 | 14.2 | 12.6 | 9.9 | 11.1 | 5.2 | 4.7 | 1.7 | 0.9 | 0.4 | 0.2 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Wind Speed (m/s)

Source:Pakistan Meteorological Department

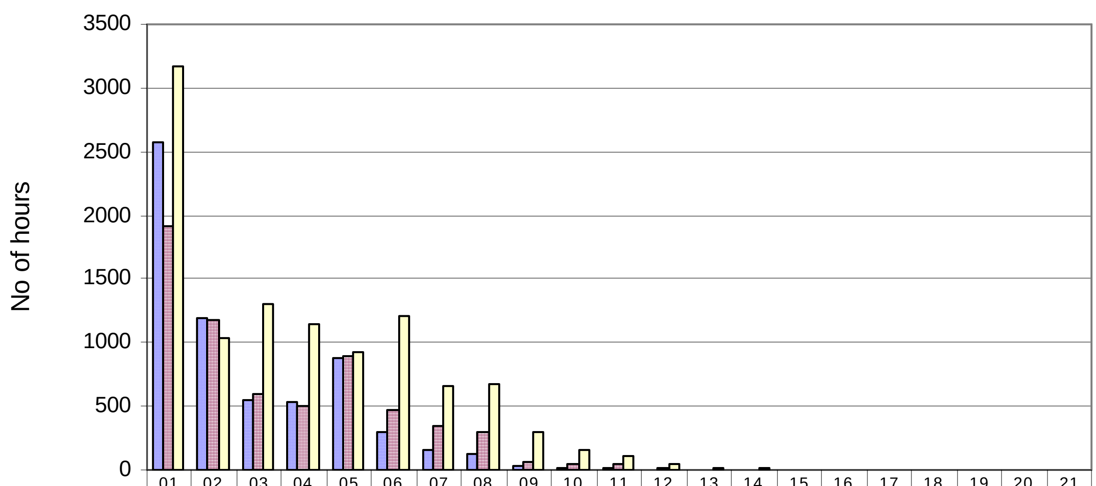
3.4.5 ***Seasonal Wind Frequency Distribution:*** Figures 11–14 gives seasonal wind frequency distribution and figures 15–18 give this distribution in percentage.

March – May

Fig-11 shows this distribution during the months of March to May in the period of three years. We can see that in this period at 50 meters height during 922 hours we get 5m/s, 1206 hours 6m/s, 662 hours 7m/s, 676 hours 8m/s, 293 hours 9m/s, 165 hours 10m/s and during 104 hours wind speed reaches to 11m/s. Similarly at 30 meters during 899 hours we get 5m/s, 470 hours 6m/s, 341 hours 7m/s, 299 hours 8m/s, 69 hours 9m/s, 43 hours 10m/s and during 43 hours wind speed reaches to 11m/s.

Fig-11

Wind Frequency Distribution at Nalent (Mar to May) in three years




| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WFD10m | 2580 | 1187 | 546 | 540 | 885 | 291 | 161 | 127 | 30 | 16 | 9 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD30m | 1911 | 1180 | 603 | 497 | 899 | 470 | 341 | 299 | 69 | 43 | 43 | 9 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD50m | 3166 | 1031 | 1309 | 1139 | 922 | 1206 | 662 | 676 | 293 | 165 | 104 | 51 | 22 | 9 | 3 | 1 | 1 | 0 | 0 | 0 | 0 |

Source:Pakistan Meteorological Department

Wind Speed (m/s)

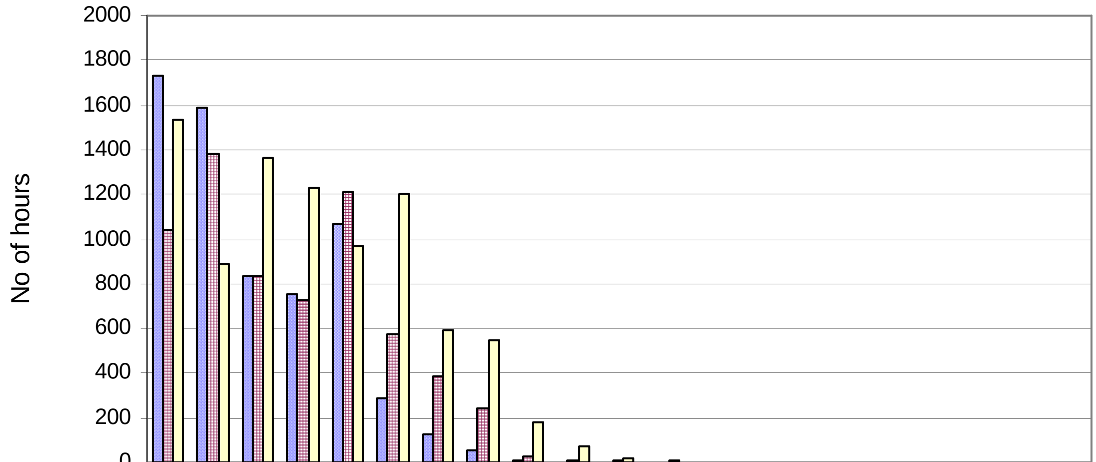
June - August

Fig-12 shows wind frequency distribution during the months of June to August in the period of three years. We can see that in this period at 30 meters height during 1214 hours we get 5m/s, 571 hours 6m/s, 383 hours 7m/s, 245 hours 8m/s, 26 hours 9m/s, 8 hours 10m/s and 5 hours 11m/s.

Similarly at 50 meters height during 971 hours we get wind speed of 5m/s, during 1197 hours 6m/s, 595 hours 7m/s, 544 hours 8m/s, 178 hours 9m/s, 68 hours 10m/s, 21 hours 11m/s and 7 hours 12m/s.

Fig-12

Wind Frequency Distribution at Nalent (June to Aug) in three years




| | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WFD10m | 1727 | 1584 | 837 | 754 | 1066 | 287 | 124 | 55 | 5 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD30m | 1043 | 1384 | 838 | 723 | 1214 | 571 | 383 | 245 | 26 | 8 | 5 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD50m | 1532 | 886 | 1365 | 1232 | 971 | 1197 | 595 | 544 | 178 | 68 | 21 | 7 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

Wind Speed (m/s)

Source:Pakistan Meteorological Department

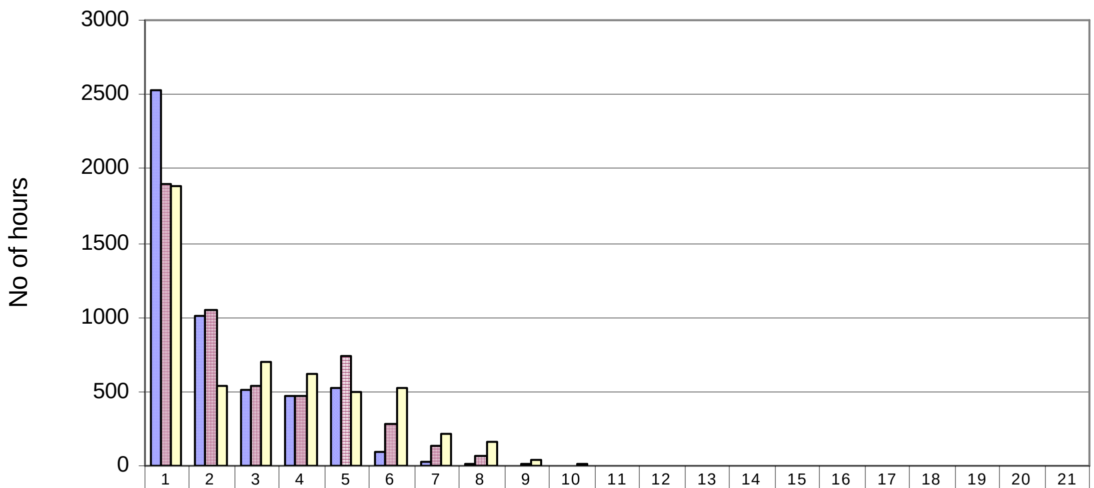
September – November

Fig-13 shows wind frequency distribution during the period from September to November in three years. We can see that at 30 meters height during 744 hours we get 5m/s, 277 hours 6m/s, 139 hours 7m/s, 73 hours 8m/s and during 7 hours 9m/s.

Similarly at 50 meters height during 493 hours we get wind speed of 5m/s, 528 hours 6m/s, 210 hours 7m/s, and 155 hours 8m/s and for 40 hours 9m/s.

Fig-13

Wind Frequency Distribution at Nalent (Sep to Nov) in three years




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WFD10m | 2532 | 1014 | 508 | 466 | 530 | 94 | 32 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD30m | 1891 | 1048 | 539 | 467 | 744 | 277 | 139 | 73 | 7 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD50m | 1883 | 537 | 703 | 616 | 493 | 528 | 210 | 155 | 40 | 16 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Source:Pakistan Meteorological Department

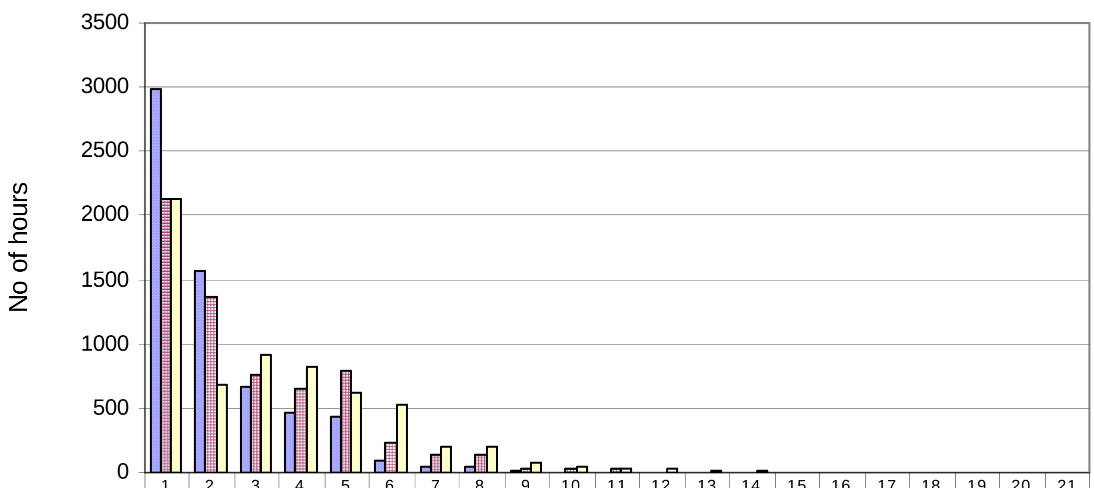
Wind Speed (m/s)

<u>December – February</u>

Fig-14 shows wind frequency distribution during the period from December to February in three years. We can see that at 30 meters height during 797 hours we get wind speed of 5m/s, 229 hours 6m/s, 146 hours 7m/s and during 133 hours 8m/s. Similarly at 50 meters during 621 hours we get 5m/s, 536 hours 6m/s, 197 hours 7m/s, 195 hours 8m/s and 85 hours we get 9m/s. Actually this is the period when we get generally lower wind potential as compared to other seasons.

Fig-14

Wind Frequency Distribution at Nalent (Dec to Feb) in three years




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WFD10m | 2991 | 1571 | 676 | 473 | 432 | 92 | 52 | 43 | 8 | 5 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD30m | 2131 | 1373 | 769 | 656 | 797 | 229 | 146 | 133 | 38 | 29 | 31 | 7 | 4 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WFD50m | 2124 | 684 | 925 | 829 | 621 | 536 | 197 | 195 | 85 | 53 | 35 | 27 | 15 | 10 | 6 | 3 | 1 | 0 | 0 | 0 | 0 |

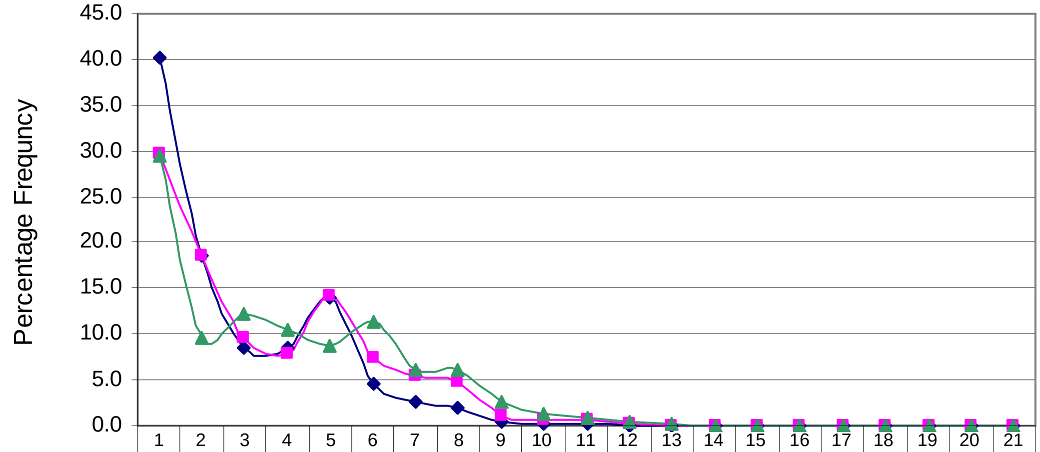
Source:Pakistan Meteorological Department

Wind Speed (m/s)

Similarly the above mentioned seasonal frequency distribution percentage terms have been presented in figures 15–18.

Fig-15

Percentage Wind Frequency Distribution at Nalent (Mar to May) in three years



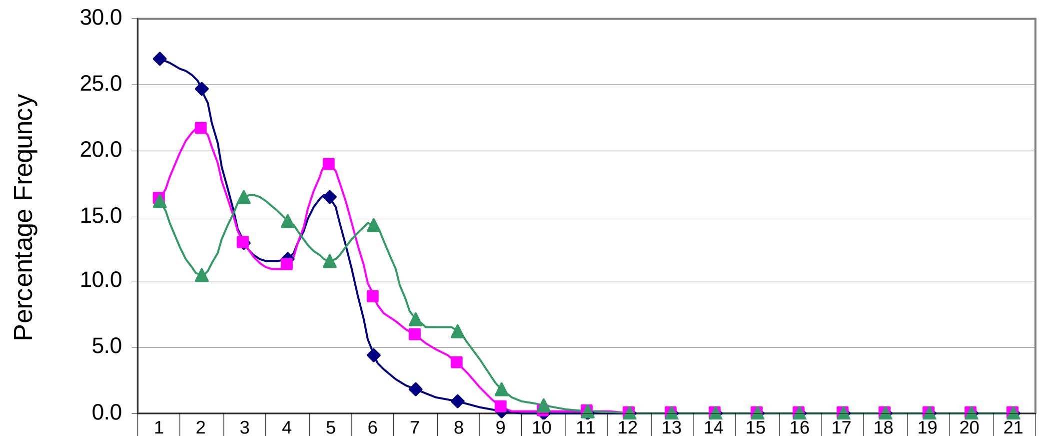

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PFD10m | 40.2 | 18.6 | 8.6 | 8.5 | 14.0 | 4.6 | 2.6 | 2.0 | 0.5 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD30m | 29.7 | 18.5 | 9.5 | 7.8 | 14.2 | 7.4 | 5.5 | 4.8 | 1.1 | 0.7 | 0.7 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD50m | 29.6 | 9.6 | 12.3 | 10.5 | 8.8 | 11.4 | 6.2 | 6.1 | 2.6 | 1.4 | 0.9 | 0.4 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Wind Speed (m/s)

Source:Pakistan Meteorological Department

Fig-16

Percentage Wind Frequency Distribution at Nalent (Jun to Aug) in three years



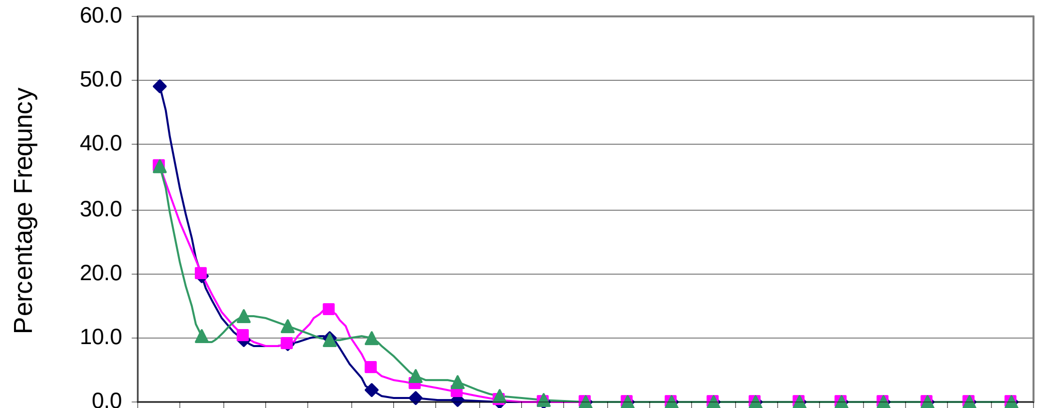

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PFD10m | 26.9 | 24.7 | 13.0 | 11.7 | 16.5 | 4.4 | 1.9 | 0.8 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD30m | 16.3 | 21.6 | 13.0 | 11.2 | 18.8 | 8.8 | 5.9 | 3.8 | 0.4 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD50m | 16.1 | 10.4 | 16.5 | 14.7 | 11.6 | 14.3 | 7.2 | 6.3 | 1.9 | 0.7 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Wind Speed (m/s)

Source:Pakistan Meteorological Department

Fig-17

Percentage Wind Frequency Distribution at Nalent (Sep to Nov) in three years



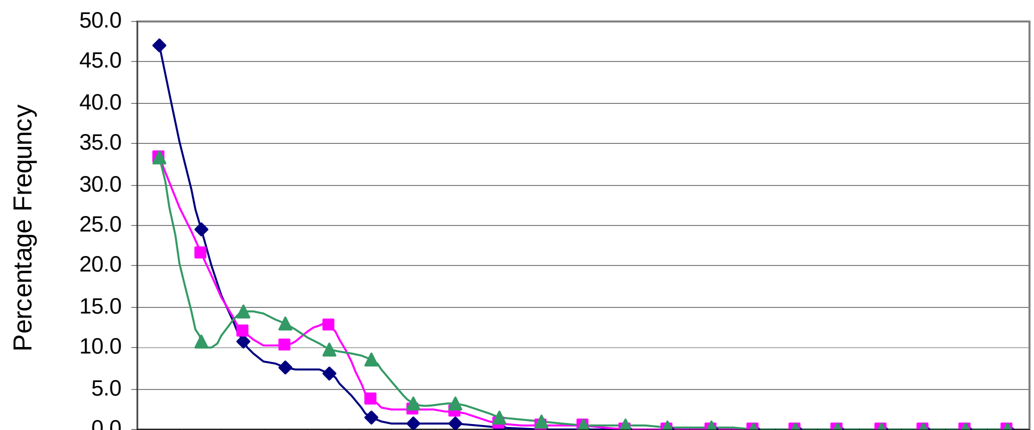

| Wind Speed (m/s) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PFD10m | 49.0 | 19.5 | 9.7 | 8.9 | 10.1 | 1.8 | 0.6 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD30m | 36.8 | 20.0 | 10.3 | 9.0 | 14.1 | 5.1 | 2.7 | 1.7 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD50m | 36.7 | 10.3 | 13.4 | 11.9 | 9.5 | 9.9 | 3.9 | 3.1 | 0.9 | 0.4 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Wind Speed (m/s)

Source:Pakistan Meteorological Department

Fig-18

Percentage Wind Frequency Distribution at Nalent (Dec to Feb) in three years




| Wind Speed (m/s) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PFD10m | 47.0 | 24.6 | 10.7 | 7.5 | 6.9 | 1.5 | 0.8 | 0.7 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD30m | 33.4 | 21.5 | 12.0 | 10.3 | 12.7 | 3.7 | 2.4 | 2.2 | 0.6 | 0.5 | 0.5 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| PFD50m | 33.3 | 10.7 | 14.5 | 13.0 | 9.8 | 8.5 | 3.2 | 3.1 | 1.4 | 0.9 | 0.6 | 0.4 | 0.2 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Wind Speed (m/s)

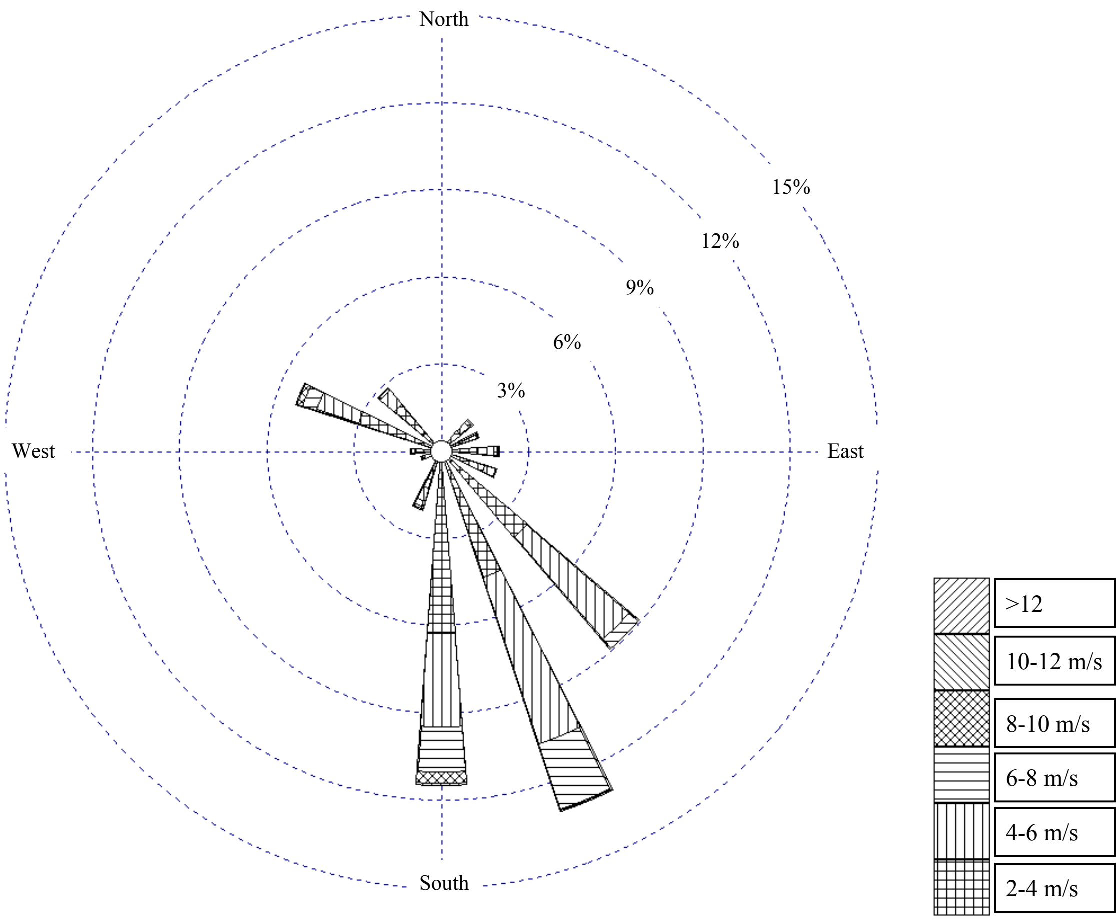
Source:Pakistan Meteorological Department

3.5 **Wind Rose:**

Fig-19 shows the Wind Rose based on three Years data from October2002 – August 2005 collected at 30 meters height. Wind Rose indicates that most of the time the wind direction was south to southeast. The annual average wind speed is 4.03 m/s and the percentage when wind speed less than 2 m/s is 46.92% only.

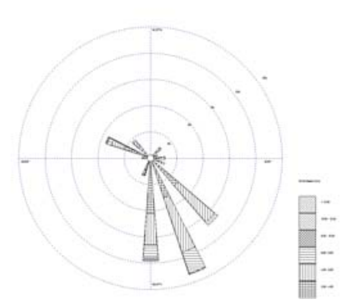
## Wind Rose at Nalent (30m height during three years)

Fig-19

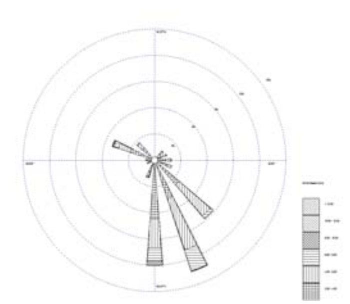



Source: - Pakistan Meteorological Department

Wind rose of first years:



Wind rose of last two years:



## 3.6 Wind speed statistic:

### 3.6.1 *The statistical Mean:*

It is the average of a set of n numbers. Mathematically, we can write

$$Mean = \frac{\left[ \sum_{i=1}^{n} x_i \right]}{N}$$

The Mean Wind Speed V can be calculated by the formula.

$$V = \sum_{i=1}^{n} V_i P(V_i)$$

Where Vi is the central wind speed of bin 1 and P(Vi) is the probability/relative frequency that the wind speed has in bin i.

### 3.6.2 *Variance:*

It is one of the several indices of variability that statistician, use to characterize the dispersion among the measures in a given set of data. Mathematically, variance is written as

$$\text{Variance} = \sigma^2 = \sum (X_i - V)^2$$

Where V is mean of data set

In case of wind speed data, we can write it, as

$$\sigma^2 = \sum V_i^2 P(Vi) - (V)^2$$

### 3.6.3 *Standard Deviation*

It is the square root of the variance, denoted by $\sigma$

$$\sigma^2 = (\sigma)^{1/2} = \sum \left( V_i^2 P(V_i) - (V)^2 \right)^{1/2}$$

## 3.7 Wind power density:

While investigating a wind power potential of an area, the average values of wind speed does not truly represent this potential because lot of information regarding frequency distribution of wind speed is suppressed in the process of averaging wind speed. As such the most important values for estimating the wind power potential of a given site is the value of the wind power density or the available theoretical instantaneous power from the wind. This available wind power in the wind is the flux of Kinetic Energy crossing the wind energy conversion system and its cross – sectional area.

Like water flowing in the river, wind contains energy that can be converted to electricity using wind turbines. The amount of electricity that wind turbines produce depends upon the amount of energy in the wind passing through the area swept by the wind turbines blades in a unit of time. This energy flow is referred to as the wind power density.

A key aspect of wind power density is its dependence on wind speed cubed. This means that the power contained in the wind increases very rapidly with wind speed; if the speed doubles, the power increases by a factor of eight. In practice, the relationship between the power output of a wind turbine and wind speed does not follow a cubic relationship. Below a certain minimum speed, the turbine does not have enough wind to operate, whereas above a certain speed its output levels off or begins to decline. In very high winds the turbine may even be shut down to prevent damage to it.

Wind power density also depends on air density. At higher attitudes, air density decreases and, as a result, so does the available power. This effect can reduce the power output of wind turbines on high mountains by as much as 40 percent compared to the power that could be produced at the same wind speeds at sea level. Air density depends inversely on temperature: colder temperatures are favorable for higher air densities and greater wind power production.

### 3.7.1 *Wind power classes:*

To simplify the characterization of the wind power potential, it is common to assign areas to one of seven wind classes, each representing arrange of wind power density at the special height above the ground. The standard International wind power classifications are shown in Table 2.

**Table-2: International Wind Power Classification**

| Class | Resource Potential | 30m Height | | 50m Height | |
|---|---|---|---|---|---|
| | | Wind Speed m/s | Wind Power W/m² | Wind Speed m/s | Wind Power W/m² |
| 1 | --- | 0 – 5.1 | 0 – 160 | 0 – 5.6 | 0 – 200 |
| 2 | Marginal | 5.1 – 5.9 | 160 – 240 | 5.6 – 6.4 | 200 – 300 |
| 3 | Moderate | 5.9 – 6.5 | 240 – 320 | 6.4 – 7.0 | 300 – 400 |
| 4 | Good | 6.5 – 7.0 | 320 – 400 | 7.0 – 7.5 | 400 – 500 |
| 5 | Excellent | 7.0 – 7.4 | 400 – 480 | 7.5 – 8.0 | 500 – 600 |
| 6 | --- | 7.4 – 8.2 | 480 – 640 | 8.0 – 8.8 | 600 – 800 |
| 7 | --- | 8.2 – 11.0 | 640 – 1600 | 8.8 – 11.9 | 800 – 2000 |

By and large, the areas being developed today using large wind turbine are ranked as class 5 and above. Class 4 areas are also being considered for further development as wind turbines are adopted to run more efficiently a lower wind speeds. Class1 and class2 areas are not being deemed suitable for large machines, although a smaller wind turbine may be economical in areas where the value of the energy produced is higher

3.7.2 ***Power of wind Energy:***

A parcel of Wind possesses kinetic energy

$$E = \frac{1}{2} m V^2$$

From this, power density is calculated as

$$P = \frac{e}{t} = \frac{1}{2} \frac{dm}{dt} V^2$$

Where $\frac{dm}{dt}$ is the mass of air following time.

From fluid dynamics, it can be proved that

$$\frac{dm}{dt} = \varphi A V$$

Volume of cylindrical cross section can be written as

$$V = \pi r^2 L \qquad \text{---------------} \quad (1)$$

Where r is radius of cylinder and L is length of it.

The wind moving with velocity V travels this distance L in time t so

$$S = L = Vt,$$

So equation L takes the form

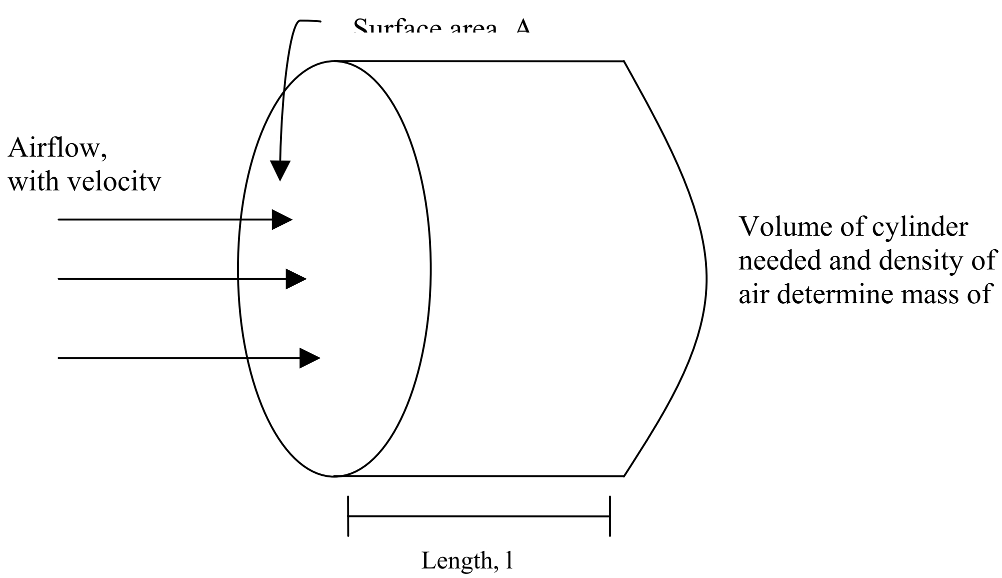
$$V = \pi r^2 V t$$

Now mass of wind can be written as

$$M = \varphi A v t$$

Differentiating $\frac{dm}{dt} = \varphi A V \frac{d}{dt(t)} = \varphi A V$

Where $\varphi$ is density of wind and others parameters have been defined in diagram.



So the power is then,

$$P = \tfrac{1}{2}\; {}^{dm}\!/_{dt}\; V^2 \; = \tfrac{1}{2}\varphi AVT / t\; V^2$$

$$= \tfrac{1}{2}\varphi AV^3$$

And power density

$$P/A = \tfrac{1}{2}\varphi V^{\;3}$$

Density of wind at mean sea level is 1.225 kg/m$^3$

At 15° C, The area depends upon the size of the rotor. Therefore, it is clear that power density chiefly depends on wind velocity and goes up as a cube of it.

### 3.7.3 *Wind power calculation using Mean wind Speed:*

Wind power calculated from Mean wind speed is not true representative of wind power. In real world, the wind varies constantly. Actual wind power density at most sites can rang from 1.0 to 3 times greater then that calculated. For example, we take wind speed of 5, 7 and 8 m/sec respectively the respective power densities are 76 watt/m$^2$, 210 watt/m$^2$ and 313 watt/m$^2$. The average of which is 200 watt/m$^2$. On the other hand, the average wind speed is 6.7 m/sec and power density of average wind is 181 watt/m$^2$. So the power of wind calculated by mean wind speed is less than the actual power present in wind i.e. Mean wind speed is not true representative for the wind power calculations.

To overcome this drawback we find some alternative arrangement, which reduces the deficit. The Weibull distribution is the best fit of wind data to calculate wind power based on mean wind speed and variance/standard deviation.

### 3.7.4 *Weibull distribution:*

The Weibull distribution (named after the Swedish physicist W. Weibull, who applied it when studying material strength in tension and fatigue in the 1930s) provides a close approximation to the probability laws of many natural phenomenons. It has been used to represent wind speed distribution for application in wind loads studies for sometime. In recent years most attention has been forced on this method for wind frequency applications not only due to its greater flexible and simplicity but also because it can give a good fit to experimental data.

The Weibull distribution function, which is a two-parameter function, has been found to fit much wind data with acceptable accuracy is expressed mathematically as

$$\phi(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} \exp\left(-\left(\frac{u}{c}\right)^{k}\right)$$

Where:

u is the wind speed

c is the scale parameter with units of speed

k is the shape parameter and is dimensionless

When k = 2 the distribution reduces to Rayleigh distribution and if k=1 an exponential distribution is found. These are special cased of Weibull distribution.

Solving the equation, we find that the scale factor c is closely related to the mean wind speed for the site.

$$\overline{u} = c\tau\left(1 + \frac{1}{K}\right)$$

Where $\tau$ is the complete gamma function

Similarly

$$\overline{u^n} = c^n\tau\left(1 + \frac{n}{k}\right)$$

And so

$$\overline{u^3} = c^3\tau\left(1 + \frac{3}{k}\right)$$

The available power density is obtained:

$$E = \frac{1}{2}\varphi c^3\tau\left(1 + \frac{3}{k}\right)$$

Where

E is the power density in watts / $m^2$

The shape factor k is related to the variance of the wind

$$\sigma^2 = c2\left[\left(1+\frac{2}{k}\right)-\left(\tau\left(1+\frac{1}{k}\right)\right)^2\right]$$

The two Weibull parameters k and c may be derived from site data.

A measure of the confidence of the fit of the Weibull curve to the real data is also returned. Often the Weibull curve is a good fit to the most of the data, but a poor fit to some. If the poor fit is in the low wind speed range, i.e. below cut in it may be possible to ignore the poor fit as this portion of wind does not contribute greatly to the overall power production.

The mathematical description of the wind frequency allows us to match with the turbine power curve. Thus a measure of the average total power capture in a year is achieved. Additionally the choice of turbine cut in and furling speed may be chosen to maximum the total energy captures.

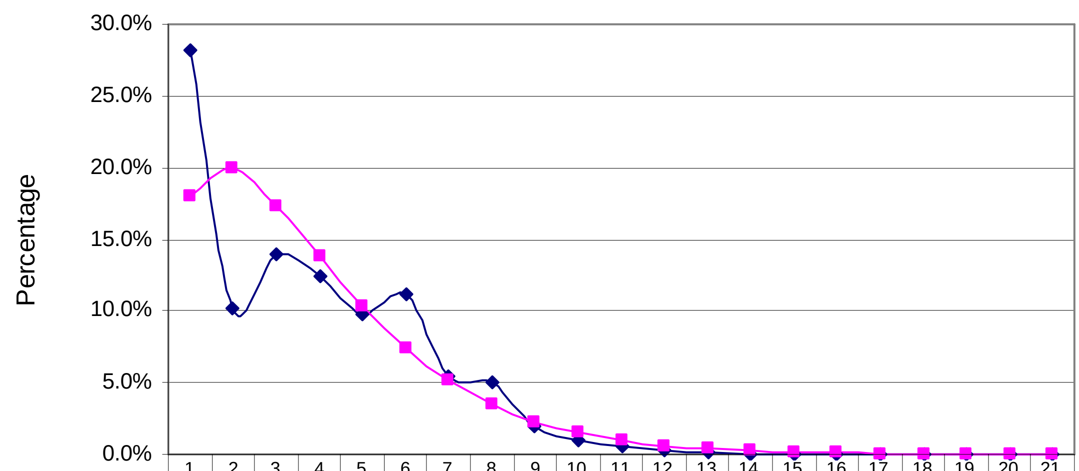
### 3.7.5 ***Weibull Parameters:***

Fig-20 shows the Weibull fit to the relative frequency of wind speed. The Weibull parameters for three different heights 10 meters, 30 meters and 50 meters are given in Table-3 along with other key results of analysis. If we look at the shape parameters K and scale parameter C for 50 meters height we can find that the shape parameter K varies over a wind range from the lowest of 1.1 in December to the highest of 1.8 in the month of July with an annual value of K being 1.3.

The lowest value of the scale parameter C 2.8m/s is observed in January, October & November while the highest value of 4.3 m/s is obtained in July and with an annual value of 3.7 m/s.

Fig-20

Relative Frequency and Weibul Probability at Nalent (50m height) in three years




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R.F. 50m | 28.2 | 10.2 | 13.9 | 12.4 | 9.7% | 11.2 | 5.4% | 5.1% | 1.9% | 1.0% | 0.5% | 0.3% | 0.1% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Weibull50m | 17.9 | 19.9 | 17.3 | 13.7 | 10.3 | 7.4% | 5.1% | 3.5% | 2.3% | 1.5% | 0.9% | 0.6% | 0.4% | 0.2% | 0.1% | 0.1% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |

Wind Speed (m/s)

Source:Pakistan Meteorological Department

3.7.6 ***Average Wind Speed & Standard Deviation:***

In Table-3 monthly average wind speed and standard deviation at three different heights are also given. The average wind speed values for 10 meters and 30 meters height have been obtained from the recorded data, whereas the values for the 50 meters height have been computed by using the power law and log law as explained in the earlier section.

At 10 meters height the annual average wind speed is 1.8 m/s with Standard deviation of ±1.8, at 30 meters this average speed is 2.6 m/s with Standard deviation of ±2.2. At 10 meters monthly average temperature from recorded data and assessed surface roughness $Z_o$ is also given. Roughness varies accordingly to the prevailing wind direction during different months.

At 50 meters the monthly average wind speed varies from the lowest of 2.3 m/s in January & October to highest of 3.8 m/s in July. Whereas the annual average winds speed is 3.1 m/s with Standard deviation of ±2.5.

3.7.7 ***Power Density:***

The monthly power densities for three different heights 10meters, 30meters and 50meters have also been given in Table-3. At 10 meters this power density varies between 8.1 W/m$^2$ in January to 58.9 W/m$^2$ in April with annual power density of 26.6 W/m$^2$.

At 30 meters height the power density varies from 22.7 W/m$^2$ in January to the highest of 95.4 W/m$^2$ in April and the annual value is about 50.3 W/m$^2$, which means that at 30 meters wind Power potential of this area falls in Class-1 which is categorized as Below Marginal potential.

At 50 meters height the power density of Nalent varies from 40.1 W/m$^2$ in January to 121.7 W/m$^2$ in December. As indicated from the values of the monthly power densities at 50 meters, we can further note that the power potential during the period is not above 200 W/m$^2$ and the annual power density of the area is 79.7 W/m$^2$, which brings the area into the below Marginal Class-1 category of power potential.

Table-3: Monthly Wind, St. Dev. and Wind Power Density at Nalent.

| Three years Average Monthly Wind Power Density at Nalent (10m) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | AvgV (m/s) | St Dev | C (m/s) | K | Temp | Zo | P/A($w/m^2$) |
| January | 1.2 | 1.2 | 1.6 | 1.2 | 19.8 | 1.769 | 08.1 |
| February | 1.5 | 1.6 | 2.0 | 1.1 | 21.4 | 1.228 | 19.7 |
| March | 1.8 | 1.8 | 2.2 | 1.1 | 25.2 | 0.655 | 28.5 |
| April | 2.3 | 2.3 | 2.8 | 1.1 | 29.4 | 0.377 | 58.9 |
| May | 2.2 | 1.9 | 2.7 | 1.2 | 30.4 | 0.417 | 35.1 |
| June | 2.3 | 1.9 | 2.8 | 1.4 | 31.5 | 0.398 | 32.0 |
| July | 2.4 | 1.7 | 2.9 | 1.5 | 30.0 | 0.424 | 28.2 |
| August | 2.1 | 1.7 | 2.6 | 1.4 | 28.8 | 0.606 | 23.8 |
| September | 1.8 | 1.6 | 2.3 | 1.3 | 28.2 | 0.840 | 20.8 |
| October | 1.4 | 1.5 | 1.9 | 1.1 | 28.0 | 0.727 | 18.2 |
| November | 1.4 | 1.4 | 1.7 | 1.1 | 24.3 | 1.213 | 13.3 |
| December | 1.6 | 1.7 | 2.0 | 1.1 | 20.8 | 1.498 | 25.7 |
| Annual | 1.8 | 1.8 | 2.3 | 1.2 | 26.4 | 0.846 | 26.6 |

| Three years Average Monthly Wind Power Density at Nalent (30m) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | AvgV (m/s) | St Dev | C (m/s) | K | Temp | Zo | P/A($w/m^2$) |
| January | 1.9 | 1.7 | 2.4 | 1.3 | 19.8 | 1.769 | 22.7 |
| February | 2.3 | 2.1 | 2.8 | 1.2 | 21.4 | 1.228 | 42.3 |
| March | 2.5 | 2.2 | 3.0 | 1.2 | 25.1 | 0.655 | 54.9 |
| April | 3.0 | 2.7 | 3.6 | 1.2 | 29.3 | 0.377 | 95.4 |
| May | 3.0 | 2.3 | 3.4 | 1.4 | 30.4 | 0.417 | 60.9 |
| June | 3.1 | 2.1 | 3.6 | 1.5 | 31.5 | 0.398 | 54.2 |
| July | 3.3 | 2.0 | 3.8 | 1.7 | 30.0 | 0.424 | 52.5 |
| August | 3.0 | 2.0 | 3.4 | 1.6 | 28.8 | 0.606 | 46.1 |
| September | 2.6 | 1.9 | 3.0 | 1.4 | 28.1 | 0.840 | 38.1 |
| October | 2.0 | 1.9 | 2.4 | 1.2 | 27.9 | 0.727 | 32.2 |
| November | 2.2 | 1.8 | 2.4 | 1.2 | 24.2 | 1.213 | 30.5 |
| December | 2.5 | 2.4 | 3.0 | 1.1 | 20.7 | 1.498 | 72.3 |
| Annual | 2.6 | 2.2 | 3.1 | 1.3 | 26.4 | 0.846 | 50.3 |

| Three years Average Monthly Wind Power Density at Nalent (50m) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Month | AvgV (m/s) | St Dev | C (m/s) | K | Temp | Zo | P/A($w/m^2$) |
| January | 2.3 | 2.0 | 2.8 | 1.3 | 19.7 | 1.769 | 40.1 |
| February | 2.8 | 2.4 | 3.3 | 1.2 | 21.4 | 1.228 | 66.9 |
| March | 2.9 | 2.6 | 3.4 | 1.2 | 25.1 | 0.655 | 82.1 |
| April | 3.5 | 2.9 | 4.0 | 1.2 | 29.3 | 0.377 | 119.7 |
| May | 3.4 | 2.7 | 3.9 | 1.3 | 30.4 | 0.417 | 94.9 |
| June | 3.6 | 2.4 | 4.0 | 1.5 | 31.5 | 0.398 | 78.5 |
| July | 3.8 | 2.2 | 4.3 | 1.8 | 29.9 | 0.424 | 76.1 |
| August | 3.4 | 2.2 | 4.0 | 1.6 | 28.7 | 0.606 | 67.2 |
| September | 3.0 | 2.2 | 3.5 | 1.5 | 28.1 | 0.840 | 56.8 |
| October | 2.3 | 2.2 | 2.8 | 1.2 | 27.9 | 0.727 | 49.6 |
| November | 2.6 | 2.2 | 2.8 | 1.2 | 24.2 | 1.213 | 50.0 |
| December | 3.1 | 2.9 | 3.6 | 1.1 | 20.7 | 1.498 | 121.7 |
| Annual | 3.1 | 2.5 | 3.7 | 1.3 | 26.3 | 0.846 | 79.7 |

# Estimated Wind Generated Electric Power output

Appendix-I

Monthly Average Diurnal Variation of Wind Generated Electric Power Output

Appendix-II

Hourly Wind Generated Electric Power Output

## 4.0 **Estimating Wind Generated Electric Power Output**

The average power output of wind energy conversion technologies (WECT) is a very important parameter since it determines the energy output over time thereby influencing the economic feasibility of a wind project. It is by far more useful than the rated power, which does not account for the variability of wind velocity thereby easily overestimating energy revenues. The average power of wind turbine, $\overline{P_{WT}}$ , is the power produced at each wind speed multiplied by the fraction that wind speed is experienced, integrated over all possible wind speeds. In integral form this can be expressed as (Maxwell et al., 2002; Borowy and Salameh, 1996):

$$\overline{P_{WT}} = \int_0^\infty P_{WT}(v)\,df(v)$$

This integral can be replaced with a summation over bins, $N_B$, to calculate the average wind turbine power (Maxwell et al., 2002).

$$\overline{P_{WT}} = \sum_{j=1}^{N_B}\left\{\exp\left[-\left(\frac{v_{j-1}}{c}\right)^k\right] - \exp\left[-\left(\frac{v_j}{c}\right)^k\right]\right\} P_{WT}\left(\frac{v_{j-1}+v_j}{2}\right)$$

Please note that the relative frequency, $f_j$ /N, corresponds to the term in brackets and the power output is calculated at the midpoint between $v_{j-1}$ and $v_j$ .

The available power at any given wind speed *v* that is convertible by a turbine is defined by (Maxwell et al., 2002 Johnson, 1985)

$$P_{WT}(v) = \frac{1}{2}\rho A C_p \eta \upsilon^3$$

Where $\eta$ is the drive train efficiency (i.e. generator power/rotor power), $C_p$, is the machine power coefficient. In an idealized wind turbine no losses are experienced and the power coefficient, $C_p$, is equal to Betz' limit (i.e. $C_{p,Betz}$ = 16/27) and $\eta$ = 1. Of course, in reality both the drive train efficiency and the power coefficient cannot be maximized. The extent to which the power output is limited by physical laws as well as engineering inefficiency is dependent on the specific characteristics of individual wind turbine types. This aspect will be discussed further in the analysis of the case study.

WECTs have a range of different power output performance curves, which need to be recognized when estimating the potential power output. The power output performance curves are not only defined by parameters such as the power coefficient and the drive train efficiency but also constrained by cut-in speed, furl-out speed and rated wind speed. Where the cut-in wind seed, $v_c$, is the minimum wind velocity to generate power from a turbine, the rated wind speed, $v_R$, is the wind speed at which the 'rated power' of a WETC is achieved and generally corresponds to the point at which the conversion efficiency is near its maximum and furl-out wind speed, $v_F$, is the wind speed at which the turbine shuts down to prevent structural damage.

To account for the above-mentioned constraints we can formulate a novel formula for the average electrical power output of a turbine, $\overline{P_{WTA}}$:

$$\overline{P_{WTA}} = \begin{cases} \sum_{j=1}^{N_B} \left\{ \exp\left[ -\left( \frac{v_{j-1}}{c} \right)^k \right] - \exp\left[ -\left( \frac{v_j}{c} \right)^k \right] \right\} P_{WT}\left( \frac{v_{j-1} + v_j}{2} \right) & (v_c \le v \le v_R) \\ \sum_{j=1}^{N_B} \left\{ \exp\left[ -\left( \frac{v_{j-1}}{c} \right)^k \right] - \exp\left[ -\left( \frac{v_j}{c} \right)^k \right] \right\} P_{WT}(v_r) & (v_R \le v \le v_F) \\ 0 & (v < v_c \text{ and } v > v_F) \end{cases}$$

The energy production of the wind turbine WE(t) over time t can thus be calculated as

$$\mathrm{WE(t)} = \overline{P_{WTA}} t$$

Another way of stating the energy output from a wind turbine is to look at the capacity factor for the turbine in its particular location. The capacity factor CF, is the actual energy output over a given period of time, WE(t), divided by the theoretical maximum energy output (i.e. this means that the machine is constantly running at its rated output) during the selected time-span, RO(t). This can be formulated as

$$CF = \frac{WE(t)}{RO(t)}$$

Theoretically capacity factor vary from 0 to 100%. In practice they usually range from 20 to 70% and mostly be around 20-30 percent. However, the economic feasibility of a wind turbine does not of course depend on the capacity factor of a wind turbine alone but also depends on the costs of alternative power systems. Therefore, a low capacity factor does not automatically render a wind turbine project unfeasible.

In order to maximize the energy output of a given wind regime the optimum wind speed, $v_{opt}$, needs to be determined. The optimum wind speed indicates at what wind velocity most energy is available in a given wind regime. It is at this particular wind speed that engineers should ensure that the power coefficient is most efficient to allow for the highest energy conversion of a turbine. The optimum wind speed can be calculated as follows (Lu et al., 2002):

$$v_{opt} = c\left( \frac{k+2}{k} \right)^{\frac{1}{2}}$$

In this regard, the power density of a turbine is a good comparative indicator to show the average power output per $m^2$ of wind swept area, *A*, at a given site. This can be defined as

$$\text{Power Density} = \frac{\overline{P_{WTA}}}{A}$$

Another important aspect of that critically determines the energy output of a turbine is elevation. In many cases the available recorded wind speed data has been measured at a lower level than the planned hub height of the wind turbine. As wind velocity increases vertically the recorded wind speed data can be adjusted using the following standard formula (Borowy and Salameh, 1996.) where $v$ is the projected wind speed, $v_i$ the wind speed at reference height, H the hub height of a turbine, Hi the reference height and α the power-law exponent.

$$v = v_i \left( \frac{H}{H_i} \right)^{\alpha}$$

α is often quoted to have a value of 1/7 and is seen as a reasonable power law exponent for even and unobstructed landscapes. However, where WECT development is planned either offshore or near woodlands or close to any other non flat terrains this value can differ subsequently and a more through analysis of α is necessary. Justus as well as Counnihan offer mathematical solution for 'fitting' α to these environments (Manwell et al., 2002).

## 4.1 Hypothetical Wind Generated Electric Power:

Hypothetical wind generated electric power output at Nalent has been estimated by using the 600KW wind turbine Bonus 600/44 MK IV type. The cut in wind speed of this turbine is 3m/s and cutout wind speed is 25m/s. Rotor diameter of this turbine is 44 meters and hub height has been taken as 50 meters. The monthly and annual wind generated electric power outputs at Nalent along with the capacity factor are given in table 4

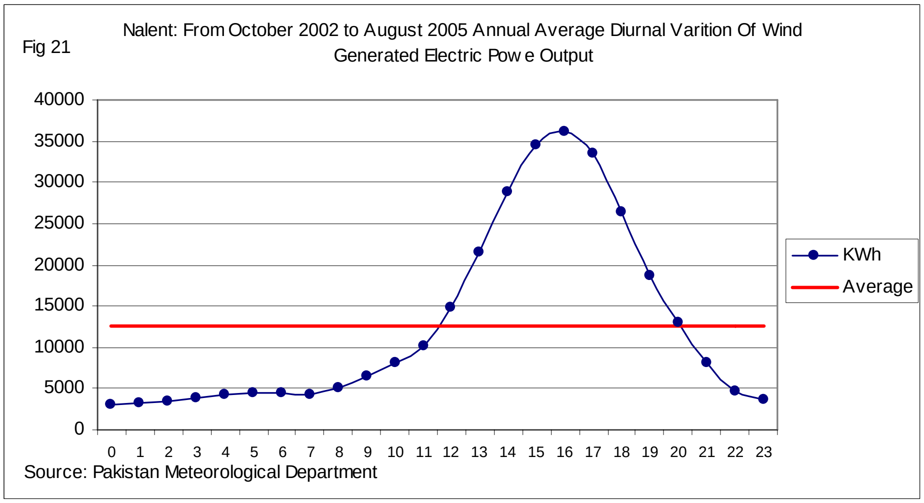
**Table-4: Hypothetical wind generated electric energy output & capacity factor for a Bonus 600/44MK IV Turbine at Nalent.**

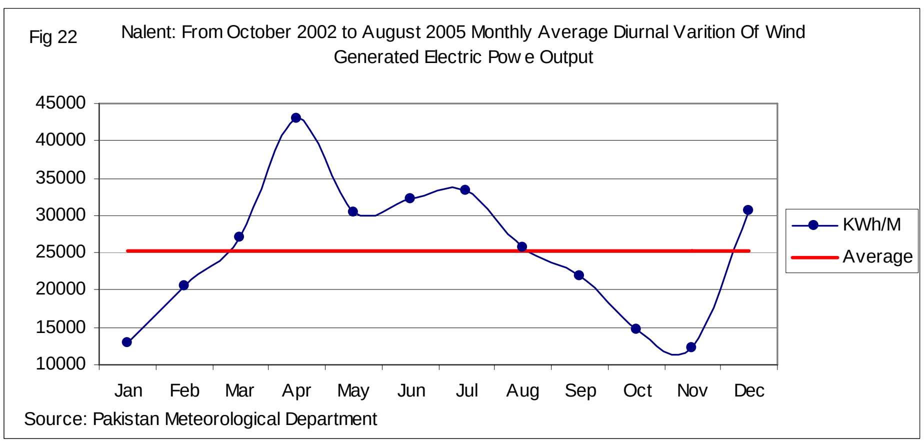
| PMD Calculator (using 50M at Nalent) from October2002 to September2005 | | | | |
|---|---|---|---|---|
| **Month** | **Input W/m²** | **Output W/m²** | **C.F.** | **KWh / Month** |
| January | 39 | 14 | 4% | 16,077 |
| February | 65 | 23 | 6% | 24,183 |
| March | 79 | 26 | 7% | 29,861 |
| April | 114 | 36 | 9% | 39,719 |
| May | 90 | 31 | 8% | 35,133 |
| June | 74 | 27 | 7% | 30,023 |
| July | 72 | 28 | 7% | 31,355 |
| August | 64 | 24 | 6% | 27,388 |
| September | 54 | 20 | 5% | 22,018 |
| October | 47 | 17 | 4% | 18,667 |
| November | 48 | 17 | 4% | 18,525 |
| December | 119 | 35 | 9% | 39,126 |
| **Annual** | 77 | 27 | 7% | 357,441 |

| Wind Turbine specification: | |
|---|---|
| Turbine | Bonus 600 / 44 MK IV |
| Power | 600 KW |
| Cut in Wind | 3 m/s |
| Cut out wind | 25 m/s |
| Rotor Diameter | 44 m |
| Hub height | 50 m |

The annual values of Table-4 are calculated using thirty-six months data and not the total or average of monthly values, therefore annual values may slightly vary with monthly values.

Figure 21 shows the annual average diurnal variation of wind generated electric energy output at Nalent. The graph shows that the maximum power is produced at about 3 to 5 p.m. of course; this is the same time when we have the maximum wind speed in 24 hours. Figure 22 & 23 shows the monthly and daily wind generated electric power output. Figure 22 depicts that at Nalent the winds have more potential in summer season as compared to that in winter season. Figures 24 to 35 shows the monthly average diurnal variation of wind generated electric energy output.



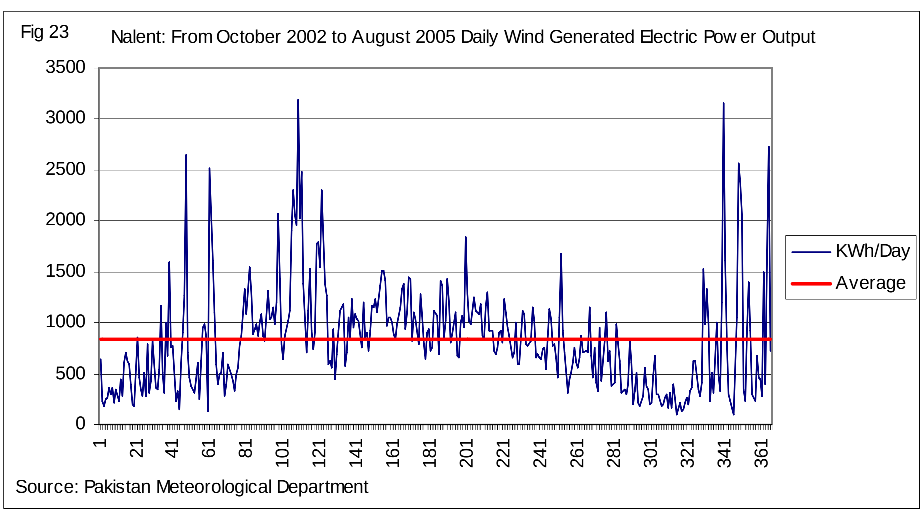
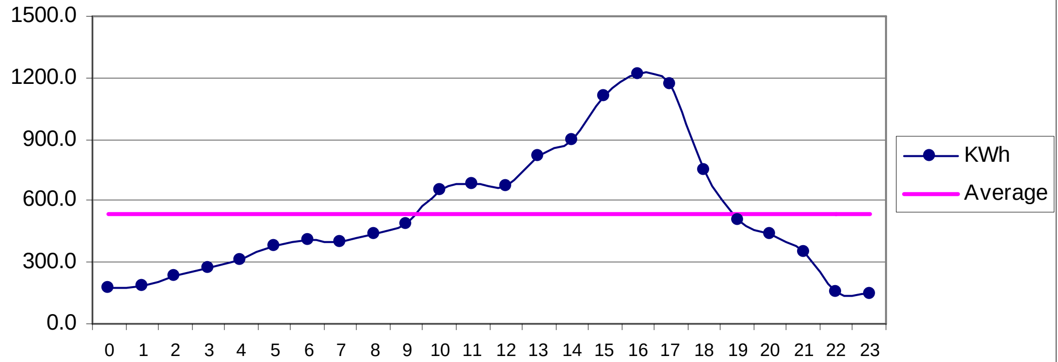
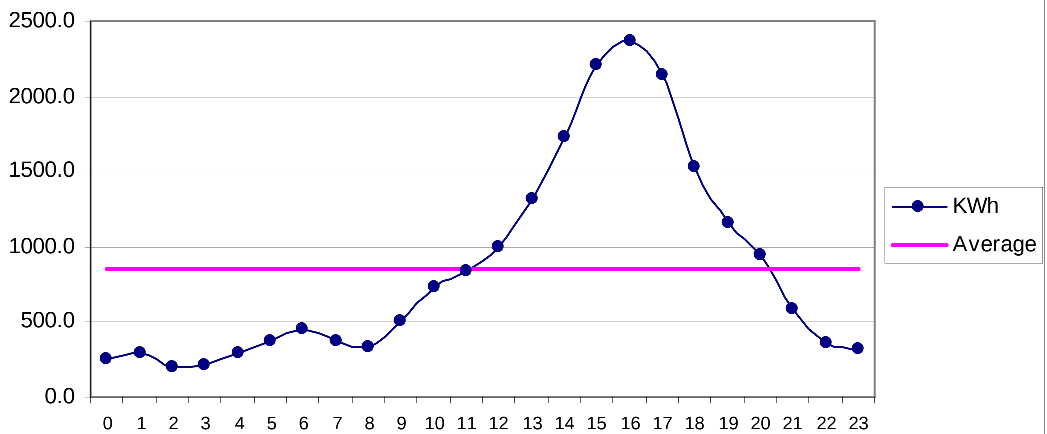



Fig 24 Nalent Jan: Diurnal Variation of Wind Genrated Electric Energy Output



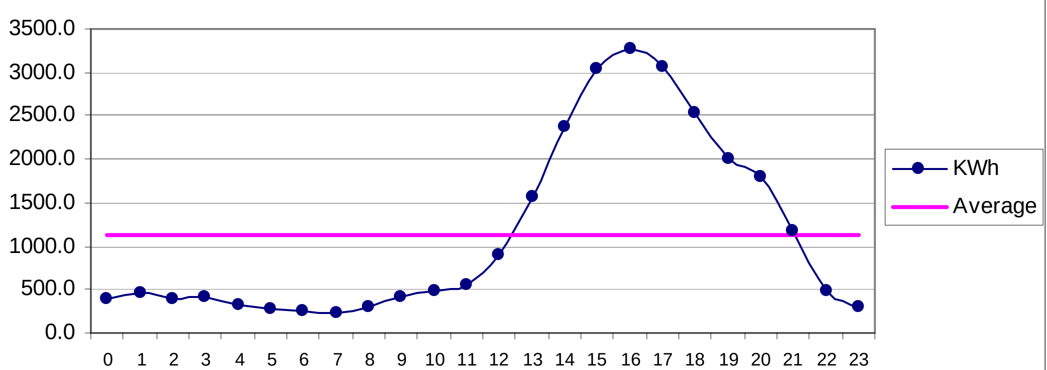

Source: Pakistan Meteorological Department

Fig 25 Nalent Feb: Diurnal Variation of Wind Genrated Electric Energy Output



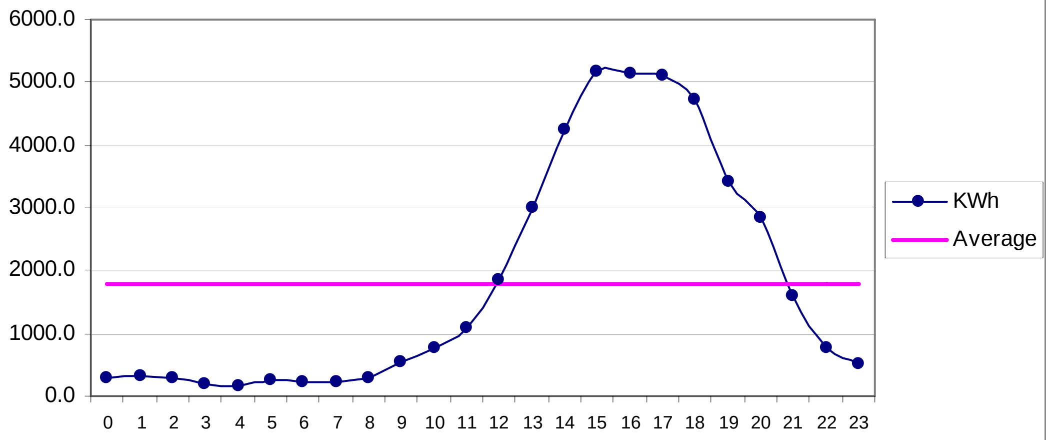

Source: Pakistan Meteorological Department

Fig 26 Nalent Mar: Diurnal Variation of Wind Genrated Electric Energy Output



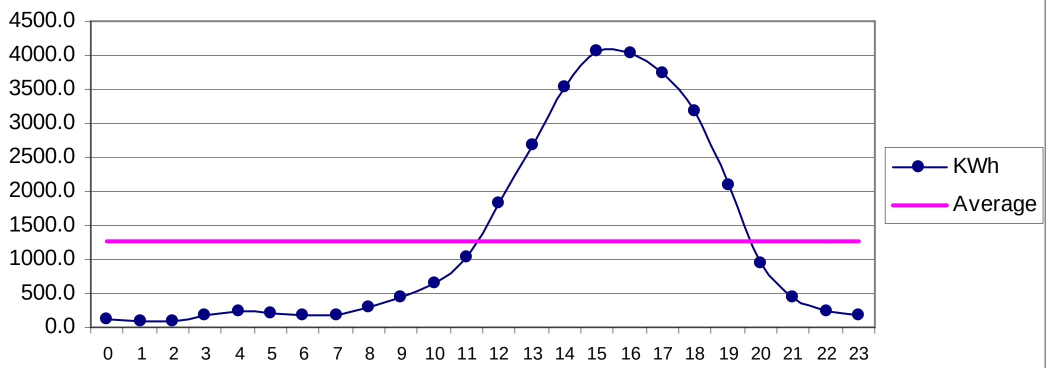

Source: Pakistan Meteorological Department

Fig 27 Nalent Apr: Diurnal Variation of Wind Genrated Electric Energy Output



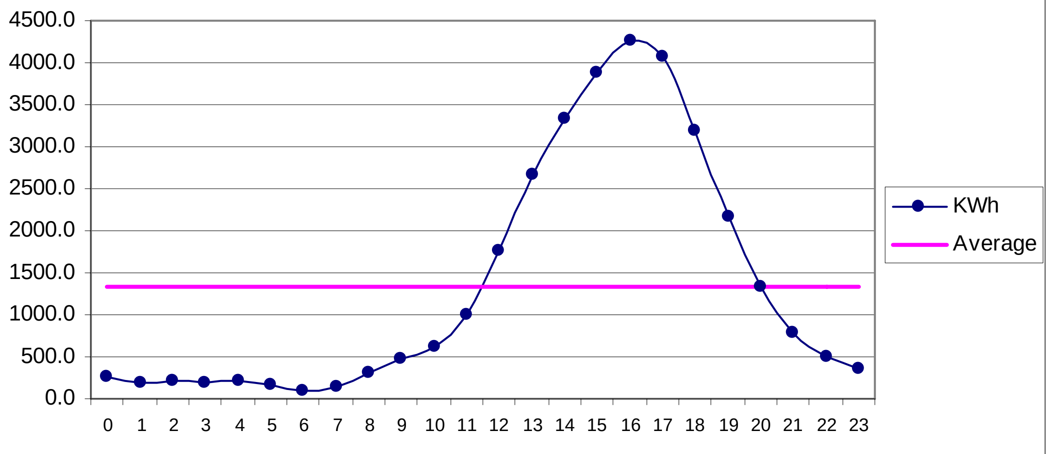

Source: Pakistan Meteorological Department

Fig 28 Nalent May: Diurnal Variation of Wind Genrated Electric Energy Output



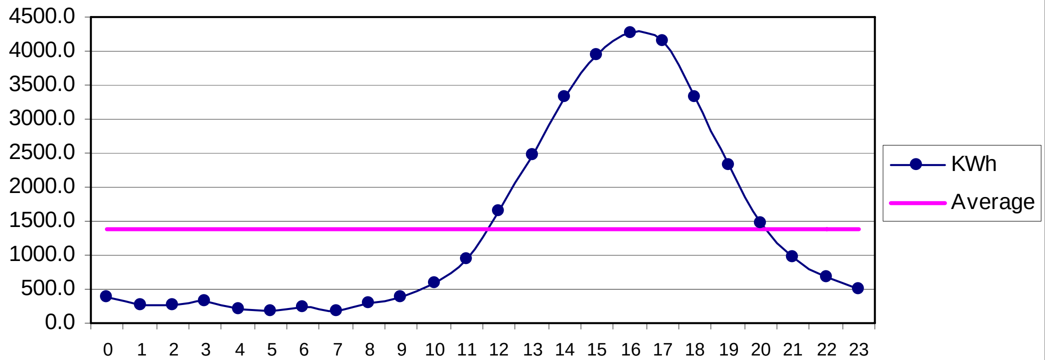

Source: Pakistan Meteorological Department

Fig 29 Nalent Jun: Diurnal Variation of Wind Genrated Electric Energy Output



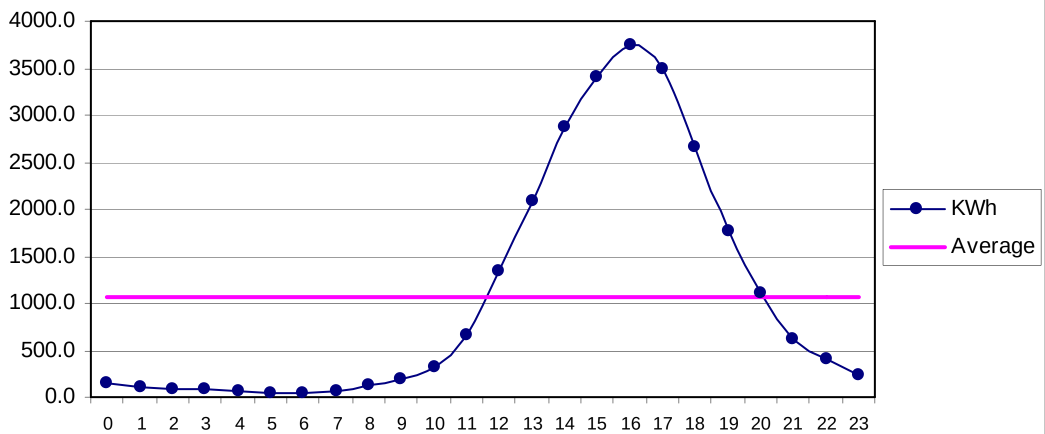

Source: Pakistan Meteorological Department

Fig 30 Nalent July: Diurnal Variation of Wind Genrated Electric Energy Output



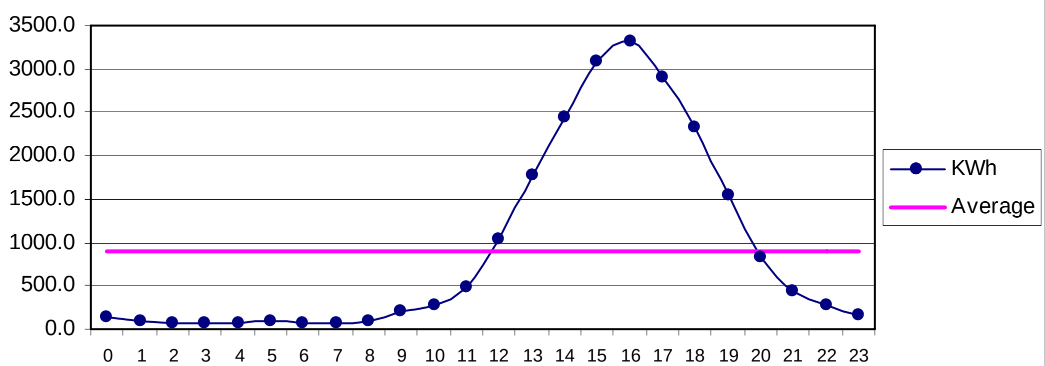

Source: Pakistan Meteorological Department

Fig 31 Nalent Aug: Diurnal Variation of Wind Genrated Electric Energy Output



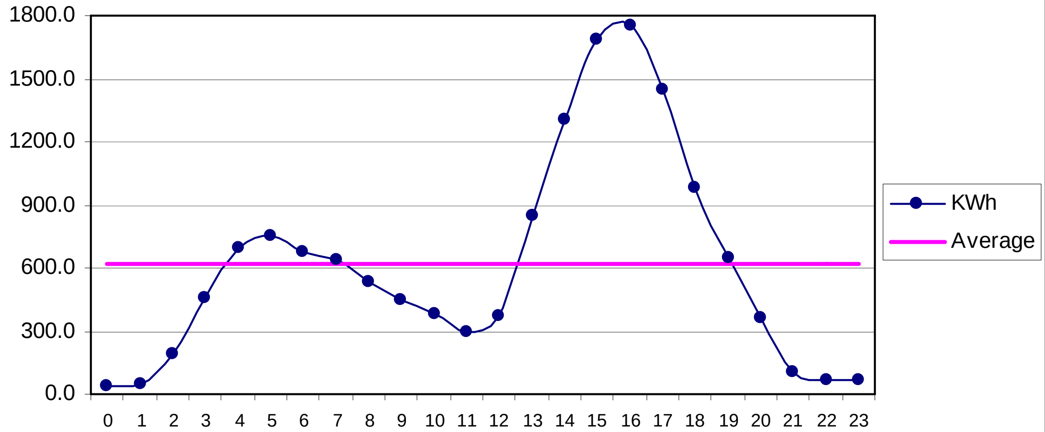

Source: Pakistan Meteorological Department

Fig 32 Nalent Sep: Diurnal Variation of Wind Genrated Electric Energy Output



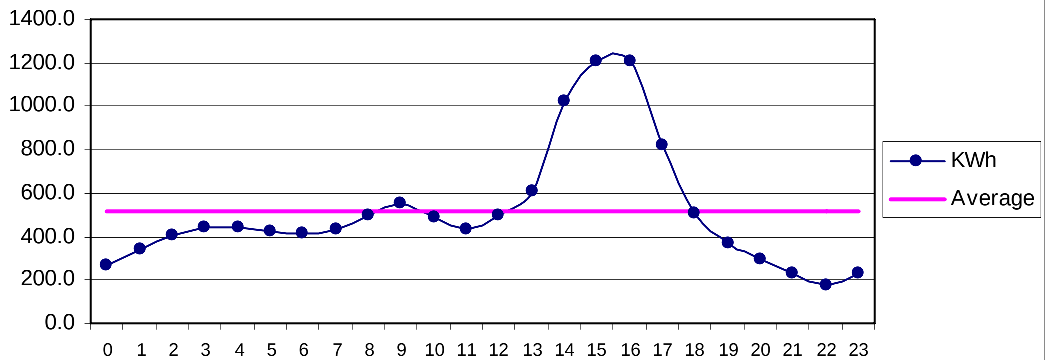

Source: Pakistan Meteorological Department

Fig 33 Nalent Oct: Diurnal Variation of Wind Genrated Electric Energy Output



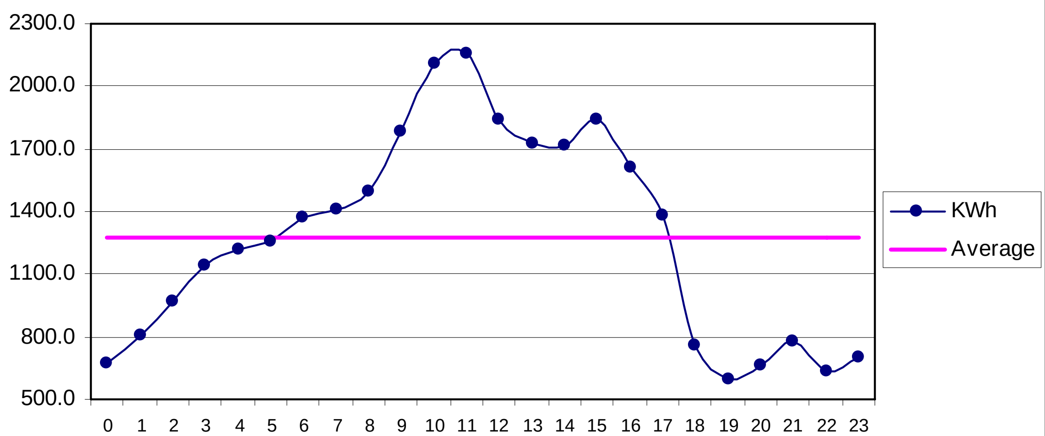

Source: Pakistan Meteorological Department

Fig 34 Nalent Nov: Diurnal Variation of Wind Genrated Electric Energy Output




Source: Pakistan Meteorological Department

Fig 35 Nalent Dec: Diurnal Variation of Wind Genrated Electric Energy Output




Source: Pakistan Meteorological Department