Analysis of wind profile for wind power station development

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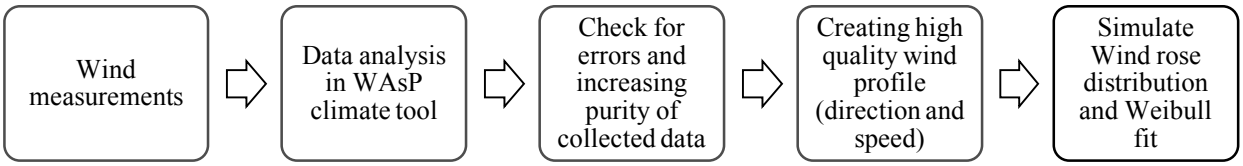
***Abstract*— Wind energy is one of the largest natural resource that can harness for sustainable energy power generation systems in the world. Wind energy was first used for grinding mills, water pump techniques since 5000B.C and now it has continuously improved to generate electricity. In wind generation technique, the Gearbox, Generator, Hydraulic system, pitch controlling, Rectification, Inverter, foundation and tower design system creates complexity in it. Sitting a wind turbine in an area should be analyzed deeply so that it cannot harm the environment and vice versa the area should be with high wind potential thus to get the predicted wind generation. According to financial modeling of wind stations, the generation cost is almost $3-5 cents/kWh and Investment cost will be $0.8-1.5 per Watt and it is very important to use accurate data for designing the system with concern and should be modeled before investing on the project about its annual energy production. This research is making an approach to identify the wind speed and wind direction measuring analysis, which is one of the key features in designing a wind station. The wind data will give a complete idea about the wind potential of the site which is the fuel for turbines to generate its maximum power under maximum efficiency. This will discuss about how to use the collected wind data to filter and edit in WaSP climate analysis tool in order to maximize the purity of the analysis and finally will model a wind profile by using actual wind measurements collected for 4 years and which can be used to model a wind power station. Finally, it will create the Observed wind climate (OWC). The wind rose, and Weibull will be distributed and fitted in the simulations accordingly, and therefore, these data can be a green indication to proceed for a wind turbine site development.**

***Key Words*— Types of wind turbines, Wind measuring, IEC standards, Met stations, Data Analysis, WaSP climate tool, WRPLOT simulation, Wind Rose distribution, Weibull distribution, WaSP tubine edditor, Anual power generation, 3D simulation.**

I. INTRODUCTION

Wind profile analysis is so important in the terms of financial aspects. Most of the shareholders or investors who is interested to get in to the field of wind technology for power generation, mainly consider about the wind profile at the proposed site. With the analyzed wind profile data, it will be decided the 'go'/'no go' for the project at the pre-feasibility study. According to International Electromechanical Commission (IEC) the wind turbines are classified in to four classes; class 1, class 2, class 3 and class 4 and all these classes of different wind turbines are used under different annual mean wind speed data observed in the wind site location [10]. Therefore, this topic is so important in wind power perspectives and it is discussed in this research about the ways of wind measurements, widely using wind measuring tools and its pros and cons, proper installation processes and finally it is using a software tool to analysis and make the error corrections in observed wind data and get a well distributed Weibull distribution. The flow chart is as follows,



II. LITERATURE REVIEW

A. The technology of wind power

Wind power technology in power generation was founded by Professor James Blyth which was built in Scotland in July 1887 [11]. It has driven the world into sustainable energy power system networks. The main working principle of the wind turbine is, using kinetic energy from wind to make the rotation of the rotor and then transfer the kinetic energy into mechanical power through rotor shaft and then use this mechanical power into electric power by connecting it to the generator and connect to the grid system with power electronic controlling integration methods as inverters. The wind turbines are developed in different ways and as an example some turbines consist planetary gearbox system to increase the rpm feed in to the generator and some turbines are permanent magnet generator without gearbox system and these are discussed below. The basic internal layout of a nacelle is shown below in fig.01.

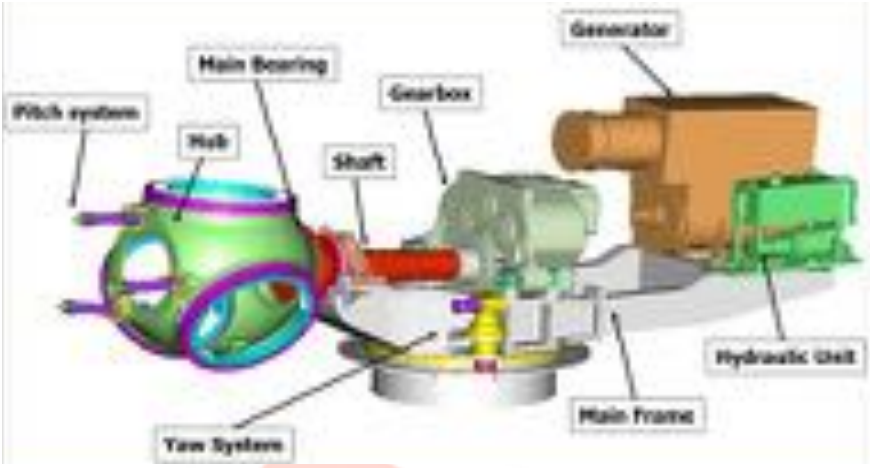


Fig. 01 Made AE59 800kW wind turbine nacelle internal structure (from Gamesa)

A.1 Types of Wind Turbine Generators (WTG)

There are many types of utility scale WTGs available in the industry, and each of these turbines will be classified according to its operations and configuration. The turbine rotor arrangement, power capacity, generator driving mechanism, grid connectivity and location of turbine installation will be under those configurations [1][2].

A.2 Horizontal and Vertical axis wind turbine

According to the placement of blades connected to the rotor, it is divided in to two main turbines Horizontal axis wind turbine and vertical axis wind turbine. (HAWT) are much common in present world and the specialty of it is rotating axis of blades are parallel to the wind stream. The recent to development of this method is because the turbine efficiency is higher, high power density, low cut-in wind speeds, and low cost per unit power output. (VAWT) are very less in use due its low power efficiency. The reason behind this effect is the VAWT will be directly installed on the ground because these types of turbines rotates with respect to their vertical axes that are perpendicular to the ground. One main advantage of this system is the wind direction is not considered due to it's design it can be operated with the wind that comes from any direction. Therefore, no yaw controlling needed [1][6].

A.3 Up wind and down wind WTG's

The HAWT can be further classified into two main categories as upwind and down wind turbines with respect to the wind flowing direction. Due to the wind velocity and to avoid unnecessary wake losses, the upwind turbines are more common than down wind turbines. Down wind turbines have an efficiency drop because the wind first meet the nacelle and tower and then the rotor blades. Thus, upwind turbines are designed to avoid all the distortion of the flow field as the wind passes though the wind tower and nacelle.

A.4 Fixed-speed induction generator WTG's

In these generator configurations there are no power semiconductor switches utilized as a part of its running condition. These generators will consume its reactive power using mechanically operated capacitor banks, and under variable wind speeds, to avoid the voltage fluctuations, these reactive capacitors will be used to regulate the terminal voltages firmly. With relevant to fast transients these terminal voltages will be reduced up to the conformance, and extensive generator power and voltages can be expected. If the frequency is varied instantaneously, the generator will be responding to the variation will be instantaneously and will limit the current, which will be similar to the synchronous generator operation [6].

A.5 Variable slip, induction generator with variable rotor resistance WTGs

The wound rotor induction generator comes with the ability to alter the successful outer rotor resistance. In this method, WTG is fundamentally the same to the operation of Fixed-speed, induction generator wind turbine. In the high wind speed area, the WTG produces consistent yield power, yield current, and output power factor. The pitch controller of the WTG is generally changed in accordance to keep the slip to be as close as could reasonably be, expected to the appraised slip when the WTG

works in high wind speed. The WTG of this sort tends to respond speedier to sudden changes than Fixed-speed, induction generator wind turbine because of its capacity to keep up the yield genuine and receptive force with the adjustable external rotor resistance and pitch controller [13].

A.6 Variable speed doubly-fed asynchronous generators with rotor-side converter WTG's

The stator output of the generator is controlled by an electromagnetic coupling, which is powered by the power converter controller. Such power converter controllers can control the generator output power of reactivity and the bus voltages. Under transient conditions, if these power controllers lose its control on the reactive power, there is a special mechanism called Crowbar which protect the DC voltage bus from getting overloaded. Thus, the temporary imbalance of mechanical aerodynamic power and electrical power output will cause to accelerate the rotor speed [14].

A.7 Variable speed generators with full converter interface WTGs

In these types of generators there is an buffer region between the grid and the generator, which will protect the generator by transients occurring in the grid side. The buffer will be stimulated by the power converter and in any fault transient, these power converters have the ability to fully control the fault. Thus, in a transient condition, if the grid voltage is reduced, the power output of the generator should be limited because, power semiconductors needed to be protected from high current inducing, and thus it will be limiting the current using power converter. In this condition, to avoid the over speeding of the turbine rotor, the pitch controller will be start to pitch out to reduce the rotor speed and which will influence in limiting the mechanical power and generator power.

B. Wind Power station configuration

A wind power station is a network that connects many wind turbines in a specified area. According to the deployed location it will be further classified as on-shore wind stations and off-shore wind stations. In an on-shore wind station, the turbines are sited in a ground location while the off-shore station, the turbines are sited in the sea using different anchoring and structural mechanisms. The figure 02 and 03 shows the on shore and off shore stations respectively [24].

Fig. 02 On shore wind station

Fig. 03 Off shore wind station

In the wind power station, the wind turbines will be commonly connected in a radial topology, which each turbine connects with radial feeders. The below figure 04 shows the single line diagram of a wind station radial connections

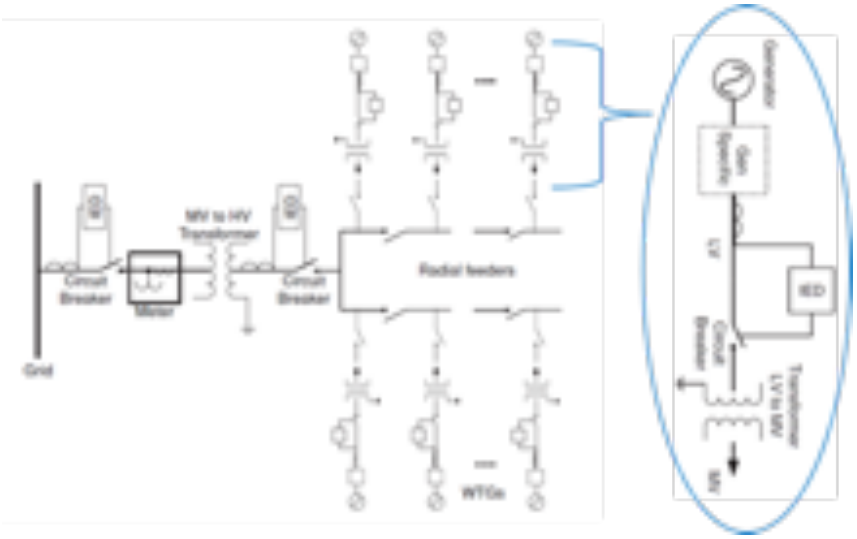


Fig. 04 Single line diagram of radial connected wind farm [6].

According to the single line diagram, the generator represents the wind turbine, and the gen-specific box indicates different components inside the generator electrical system such as, slip controlling, capacitor banks for compensations, power electronics, AC to DC and DC to AC converters, earthling's and etc. The term IED stands for intelligent electric devices such as, program logic controllers (PLC's), motherboards, fiber optic communications and independent programmable circuit breakers, which will be used to monitor different parameters of voltage, current and frequencies. The transformer is used to step up the voltage levels from 480V or 690V to 11kV or 69kV depending on the power station design capacity. Switchgear, transformers and load break switches (LBS) are used to isolate the turbines from the circuit and as well as protection. Commonly used switchgears are SF6 (Sulphur Hexa Fluoride). The feeders will be collecting the power from each turbine and connect to a common bus bar. The meter that is use in power stations can be classify as smart meters because these meters are bidirectional measuring which enable to measure import power and export power [21].

C. Factors should be considered in modeling wind power station

Wind power station development cost is higher due to its complexity. Thus, to obtain the accurate power generation simulation results it is important to collect many environmental factors that will influence on the final modeling results. This modeling is so important because with its predicted generation patterns, financial modeling will calculate the internal rate of return (IRR), Net present Value (NPV) and most importantly the tariff rate for per kWh. Therefore, it is the most critical part in a wind project implementation [25]. In designing a wind power station the roughness class and length is needed to be identified initially. According to the European Wind Atlas the different roughness classes and lengths are mentioned below,

Table 01. Roughness classes and lengths [19].

Roughness class	Roughness length, Z0 [m]	Landscape
0	0.0002	Water surface
0.5	0.0024	Completely open terrain with a smooth surface, such as concrete runways in airports, mowed grass
1	0.03	Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills
1.5	0.055	Agricultural land with some houses and meter tall sheltering hedgerows within a distance of about 1250 meters.
2	0.1	Agricultural land with some houses and 8 meter tall sheltering hedgerows within a distance of about 500m.
2.5	0.2	Agricultural land with many houses, shrubs and plants, or 8 meter tall sheltering hedgerows within a distance of about 250 meters.
3	0.4	Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain.
3.5	0.8	Large cities with tall buildings
4	1.6	Very large cities with tall buildings and skyscrapers.

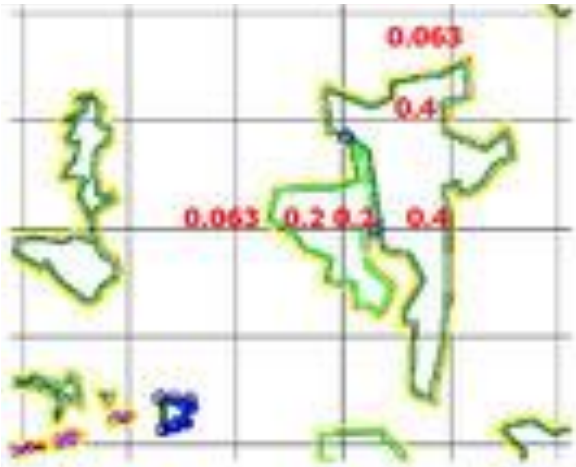


Fig. 05 Roughness classes in map

The roughness class will be expressed by roughness change lines. Each line has a pair of right and left-hand roughness lengths (m) as attributes. Different color patterns will indicate its unique roughness's as shown in the figure 05 [20]. Apart from the roughness classes and lengths there are many considerations should be full fill in order to design a wind station. Such as,

1. Orography effects
2. Wind speed and direction data
3. Terrain analysis
4. Obstacles and its effects

Out of the above 4 factors, this research will be focusing on the wind speed and direction data as it takes a key importance throughout the project lifetime [26]. Wind speed and direction data measuring

Wind speed can be measured by two ways, one is In Situ measurement and Remote Sensing. The In situ measurement requires that the instrumentation to be located directly at the point of interest and in contact with the subject of interest [3] These In situ measurements are done using meteorological tower (Met-Tower) and remote sensing is done with SODAR (Based on sound waves) or LIDAR (Based on light waves) [2]. Met-tower is used to measure wind speed, wind directions, temperature etc. Met-tower data are called permanent if the life of the met station is 20 years and common heights of met towers are 30m, 50m, 60m,80m, and 100m. The most popular height is 60m.

The wind speed velocity vector is partially averaged and cup anemometers will measure wind speed in small volume and remote sensing systems will measure large volume wind speeds. There are 3 types of anemometers to measure wind speed.

1. Cup anemometer

Fig.06. cup anemometer

2. Propeller anemometer

Fig. 07 propeller anemometer

3. Sonic anemometer

Fig. 08 Sonic anemometer

The wind speed of a given location is measured using a Cup Anemometers at different height levels. Advantages of these cup anemometers are it is robust, linear, simple calibration, stable calibration and low power consumption [6]. The rotational speed varies with wind speed and typical output will be pulses per revolution basis. The wind speed will be given by number of pulses in 10 minutes. Resolution of the instrument is 20Hz and it is more suitable for measuring wind speeds under rapid changes. Anemometers are classified according to IEC standards. The flow distortion is done according to IEC 61400-12-1 standard which guidelines of mounting of instruments on the meteorological mast considering accuracy of measurement which is indicated with a class index; k' which is a value between 0 – 3 and terrain of measurement which indicates with letters A, B and S. Class 0 is unrealistic since it is hard to achieve and class 3 is low accuracy. All these cup anemometers need to calibrate before use and these calibration process will be conducted using 0 – 16m/s wind speed variation in a wind tunnel. As per the IEC standards there are important details to be considered when deploying an anemometer tower. The Optimum direction is at 90^0 (lattice) or 45^0 (tubular) to prevailing wind direction, also the boom length should be in a lattice mast, 4 times greater than mast side width and in a tubular mast, length should be 6 times greater than mast diameter and these guidelines are given in order to avoid tower shadowing effect and minimize the flow distortion less than 1% influencing from mast. Fig,09 and 10 are respectively the triangular lattice mast at optimum boom direction of 90^0, and cylindrical tubular mast at optimum boom direction of 45^0[7].

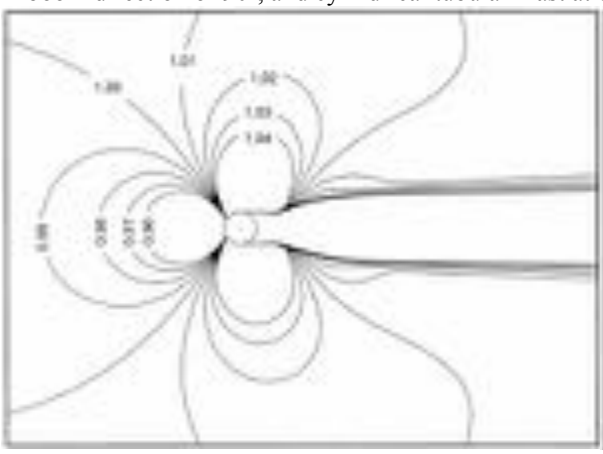


Fig. 09 triangular lattice mast at

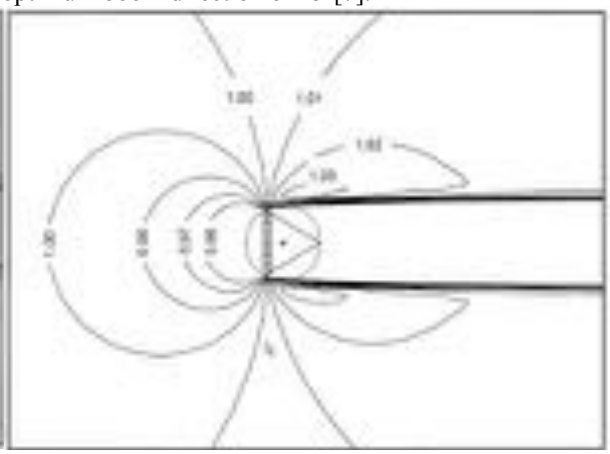
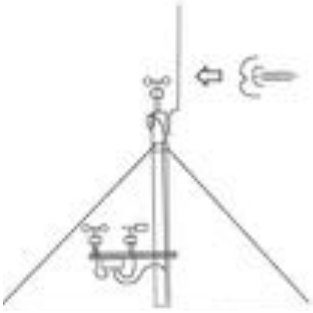


Fig. 10 cylindrical tubular mast at

optimum boom direction of 90^0 optimum boom direction of 45^0

Fig,11 and Fig,12 will expose respectively both ways of poor and good deploying method of a wind anemometer to make a clear visualization and understanding of what was discussed above.



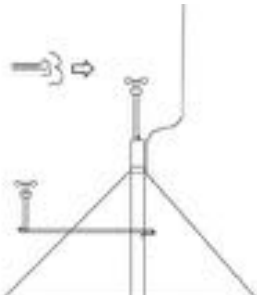


Fig. 11 (poor installation) Fig. 12 (good installation)

The propeller anemometer is also named as windmill anemometer. It is mounted parallel to the wind and this will follow the wind direction using its tail effect, [4] but some propeller anemometers have the helicoid shaped blades, and to obtain the momentum it is needed to fulfill both drag and drift forces on the blades. In fact, the measured wind speed in this system will be somewhat less than the horizontal actual wind and also if the alignment of mounting of propeller is different from the wind direction, there will be even greater wind speed measurement deviations.

Fig. 13 propeller anemometers mounted in 3 different directions

The sonic anemometers will use ultrasonic waves to measure wind speed and wind directions depend on the geometric conditions. The angular transducers are used to measure the flow speed and it can be two or three dimensions. Among the above mentioned 3 types of anemometers the widely used anemometer is cup type mechanical anemometer since it is a well-known technology and people are aware with its errors as well, and know how to eliminate these errors in obtaining readings of a specific climate condition. Even though sonic anemometer is advance, it is not commonly used because of its higher cost and higher power consumption. Also, the accuracy of sonic anemometers is low than a high-quality cup anemometer. At some point, these sonic anemometers provide advantages over cup anemometers in different ways such as it can measure the turbulence, air temperature and atmospheric stability [6][7].

All the above discussions are based on mounting on masts. Remote sensing systems are ground based and there are two main types of remote sensing instruments. Those are Sodar (Sound Detection And Ranging) and Lidar (Light Detection And Ranging) which use sound and light emission with Doppler effect. There are various types of Sodars available currently. The Phased array Sodar is the most commonly used and it can change the direction of the sound array which is created by the loud speaker with using an electronic steering interface tilting method. In this method it will be generated three-dimensional velocity field by using three beams, such as; one is the vertical direction, and other two are tilted to the vertical and perpendicular to each other's axis as shown in fig.14. The disadvantages of the Sodar system are, [08][06]

1. Temperature fluctuations 2.External noise functions can influence on solar acoustic system 3.Increase background noise due to high wind speeds 4.Vertical alignment of the system can influence on Sodar accuracy 5.Temperature changes in antenna 6.Changes in wind direction

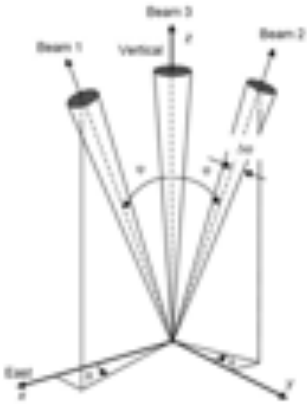


Fig. 14

Fig. 15 Sodar system

Lidar equipment transmits a laser beam as a continuous wave or as a pulse into ABL (Atmospheric Boundary Layer) and measures the scattered radiation received back at the instrument. In simple terms, the backscattered LIDAR signal can be described as,

$$P(R) = K.G(R).\beta(R).T(R) \tag{1}$$

Where, K is the performance of the system, G (R) is the range dependent geometric factor, $\beta(R)$ is the backscattered coefficient at distance R, and T(R) is the transmission factor (Light loss from Lidar to distance R and back). Regard to the properties of light, Lidar has higher accuracy and signal to noise ratio than a Sodar system. The function of Lidar can be influenced by atmospheric conditions such as fog, density of air particles and rain. Thus, the Lidar optical window should be cleaned frequently to avoid dust deposits which will influence on the accuracy of the wind data [9].

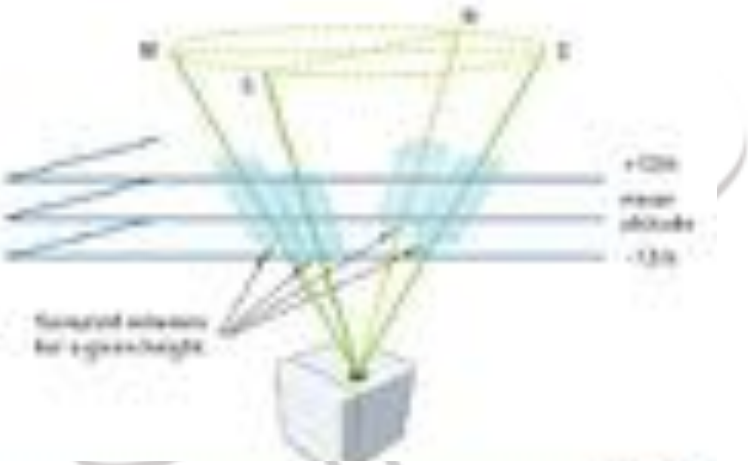


Fig. 16 Lidar Measuring system

With respect to all the systems, Lidar is much more expensive, and it was only used in military and aerospace related systems. Currently all these methods have been used to measure wind speed and its direction to design and model wind power stations around the world, but some are still needing to proceed with the cup anemometer technology because it is much convenient in use and inexpensive. It is shown above, that all these methods have its own errors in data measuring and therefore, it is a must that to filter and clear all these error data before using it for an actual design process of a complete wind power station [5].

D. Wind data analysis and error elimination

These obtained data can be used to develop a climate analysis, and the WAsP climate analysis tool will provide with many options to the user to create an observed wind climate profile that can later use in the wind station designing. General inputs which WAsP climate analysis software need is, anemometer height above ground level, anemometer location (Latitude, longitude) and collected data for minimum of 2 years. After the inputs, it is possible to map the collected data as shown in below figure.17 for editing and making the data error corrections.

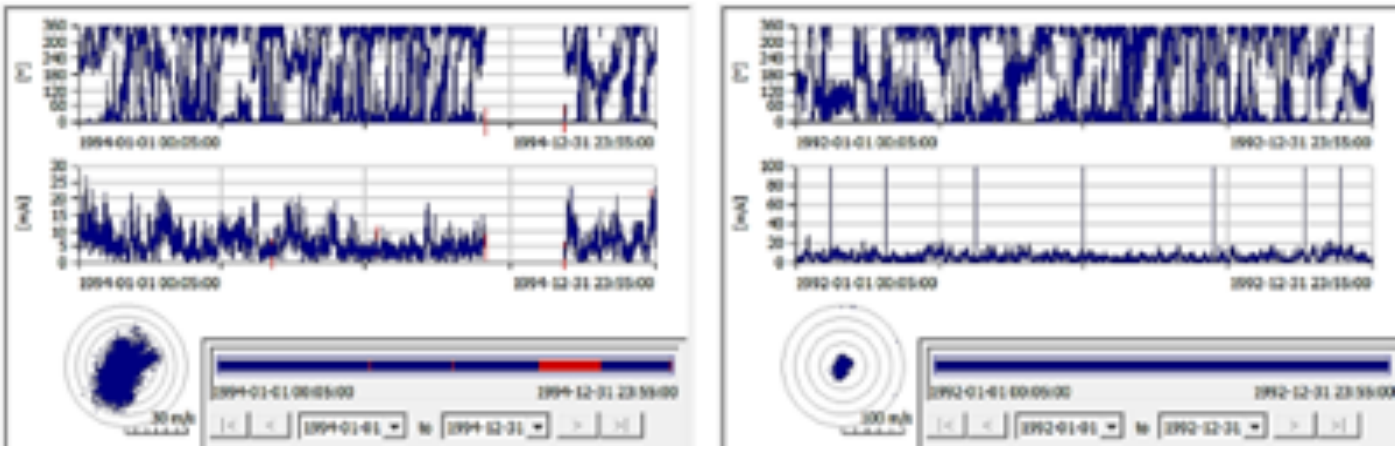


Fig. 17 Example of wind data and direction mapped in WAsP the climate analysis

The climate analysis checks the time stamps, missing records and observation intervals. Even though, it is important to check visually whether there are any spikes or sudden drops, periods of constant data values, periods of missing data, any unusual patterns, any unusual patterns in the polar scatter plot, wind speed time traces look similar for different anemometers, wind direction time traces follow each other for different vanes, measured and Weibull-derived values of U and P compare well, calm class (0-1 ms^{-1}) in the histogram look realistic in the data series. The output of these data is a wind rose and the wind speed distributions in different sectors. A Weibull distribution function is then fitted to the measured histogram to provide scale and shape parameters 'A' and 'k' for each sector shown as an example in figure.(18) [27

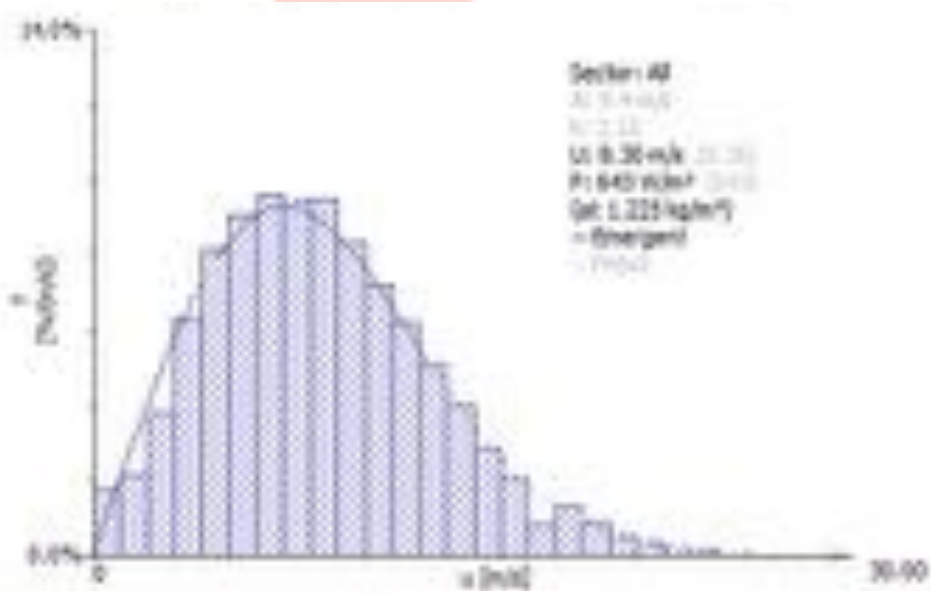


Fig. 18. Example of the output of an analyzed MET data of wind data in WAsP 2012

Since the wind speed is a variable and thus it is important to predict the production of wind turbines, it should be observed how often the wind blows and its strength. These data will be given by wind measurements which collects from the met stations. Therefore, using the frequency distribution, the energy contain in each plot of the site direction can be expressed. Thus, the Weibull is a good approximation of the wind speed distribution.

$$f(v) = \frac{k}{A}\left(\frac{v}{A}\right)^{k-1} \exp\left(-\left(\frac{v}{A}\right)\right)^{k} \tag{2}$$

The (⊆) represents the Weibull scale parameter in m/s which measure characteristic wind speed distribution and its proportional to mean wind speed (ℎ). The (ℎ) represents the Weibull form parameter and create a shape of a Weibull distribution which is a value between 1 and 3. If (ℎ) is small it represents the winds are more variable and if (ℎ) is large it represents that the wind speeds are much constant [15].

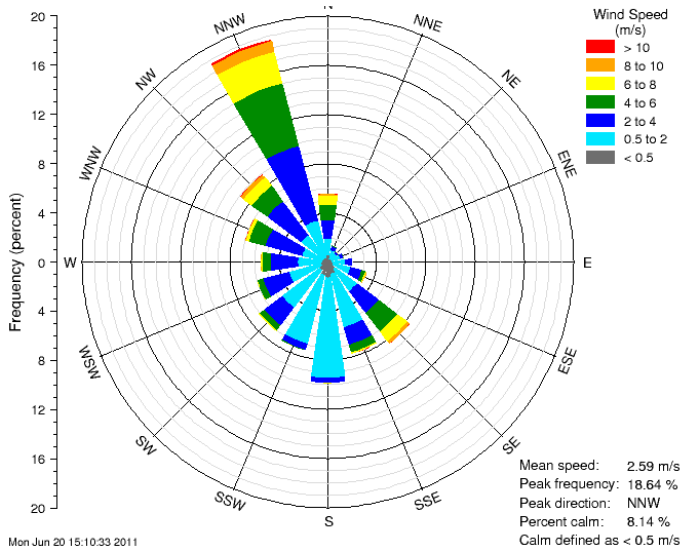


Fig.19 Wind rose distribution. South Shore Met station.US Geological Survey [17]

Wind Rose, is a diagram which plotted using data of wind speed and wind direction in a specified location. It's distribution has lengths in its particular angles which its proportional to the frequency with which wind blow in a specific direction. In standard wind rose distribution, it can be arranged the 360 degree of directions in to 8,12,16,24 and 36 sets as per the requirement. This analysis is important when sitting wind turbines in a given site [16]. The turbines should be sited in a way that it won't create a wake effect on the adjestent turbine. If the turbines sited as mentioned in the below figure.20 under the high frequency wind rose section, there will be a significant power loss.

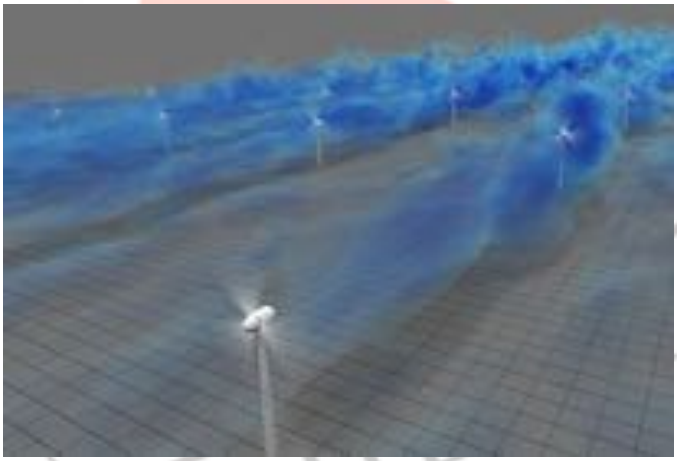
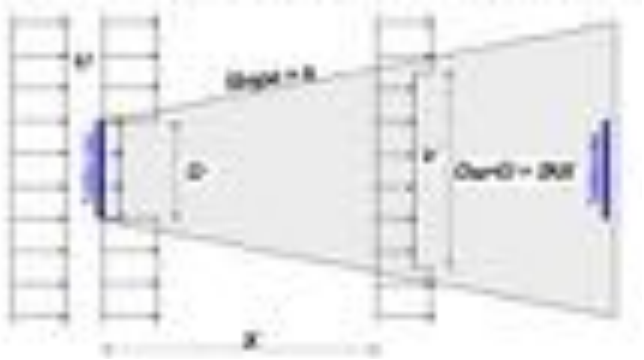


Fig. 20 Wake effect three-dimensional visualization of the flow in wind farm

(The blue color region shows the volume-rendering of low-velocity wind regions.)[18]

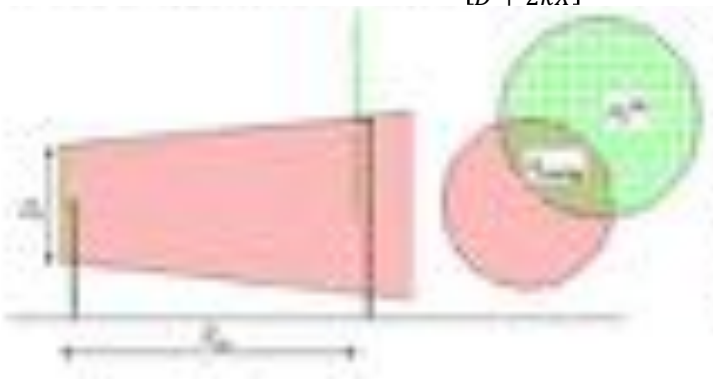


k: wake decay

constant

Wake loss is often 4-5% or less

$$\delta V = U - V = U(1 - \sqrt{1 - C_t}\,)\left[\frac{D}{D + 2kX}\right]^2 \tag{3}$$



$$\delta V_{01} = U - V_1 = U_0\left(1 - \sqrt{1 - C_t}\right)\left[\frac{D_0}{D_0 + 2kX_0}\right]^2 \frac{A_{overlap}}{A_1^{(R)}} \tag{4}$$

Fig. 21 Wake effect principle and model for speed deficit [22]

III. METHODOLOGY, SIMULATION AND RESULTS

For the simulation purposes it is need at least two years of wind data to create more accurate wind profile for a wind site development project. Therefore, in this paper it is taken 4 years of wind speed and direction measuring data to create more accurate wind profile analysis. The met location selected was Sprogoe in Denmark and the observed wind height was 70m a.g.l. Figure 22 shows the google earth view of the location with the red dot is the met station location.

Fig.22 Sprogoe Denmark. Google earth image. Met station($55^0$19’51.46’’/$10^0$58’28.18’’E)

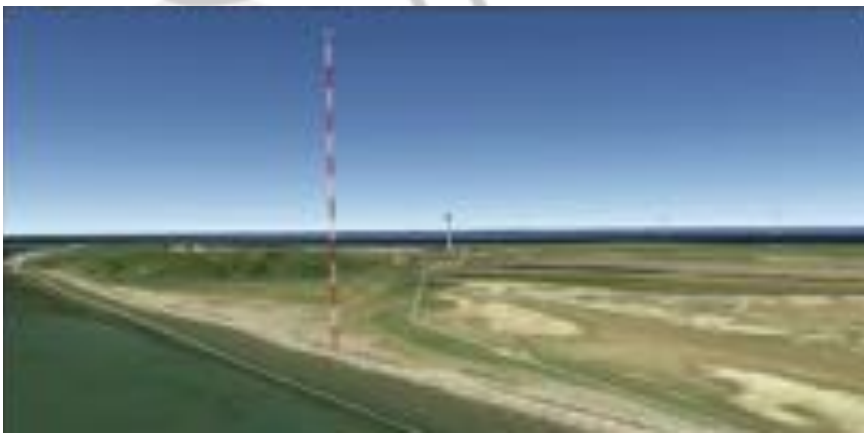


Fig. 23 70m height met station placement using google earth and Climate analysis software (3D view)

With the help of scaled map of the real location and downloading the STRM map file from WAsP map edditing software it was created the roughness classes in the given location and placed the met station as mentioned in the below figure 24 and 25.

Fig.24 Map of Sprogoe with roughness classes and met station positioned
(Elevation is mentioned in the map and grid dimensions are also mentioned)

Fig. 25. Google earth sync with STRM roughness edited map

This island outer boundary roughness is taken as zero (0) according to the European Wind Atlas roughness classification of water. The inner boundary roughness has taken as two (2) because of the geographical condition of the land surface. Point A' in the map is where the met station sited.

From the met station it was taken 1987,1988,1989, and 1990 data series for analysis. Each has recorded data from January to December complete 12 months. These collected data will be plotted in WAsP climate analysis tool for visual observation and purification. The data plot for year 1987 is as shown in figure.26,

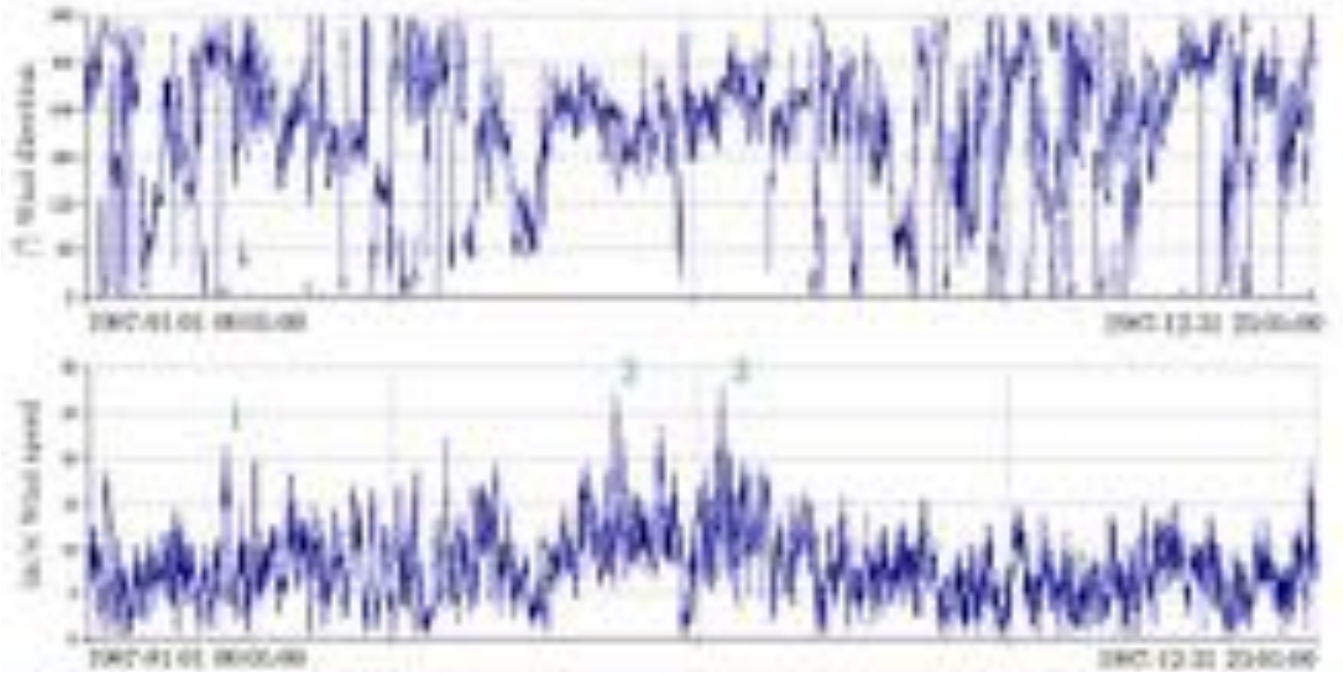


Fig. 26 Measured wind speed and direction data. Year 1987

As per the data, it is marked the unusual patterns of wind flow in the year 1987 accordingly and it is important to analyze it closely to increase the accuracy of wind profile,

On 1987-02-12 from 19:46:38 to 22:24:32 there has been missing data as shown in below figure 27.

Fig. 27 missing data time series.

Even this error is not relatively significant, since the missing time period is small, it is important to consider these errors also to get a high reliable and accurate wind profile for power station designing. Therefore, this error has eliminated by cropping the missing data series and merging ends of series together.

On 1987-06-06 at 15:16:42 and 1987-07-08 at 04:37:20 there has been an increment in wind speed up to 27.10m/s and 27.90m/s respectively as shown in the below figure 28 and figure 29.

Fig. 28 wind speed increment on 1987-06-06

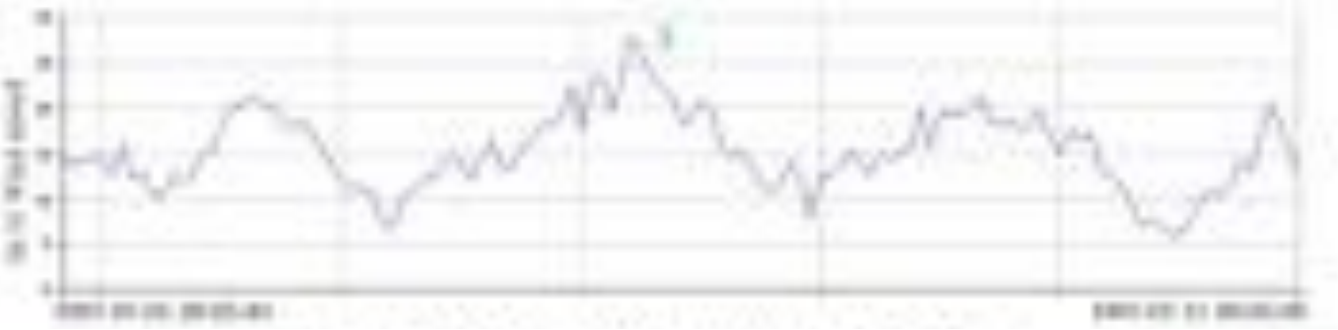


Fig. 29 wind speed increment on 1987-07-08

Thus, if it is zoomed and increase the resolution of the errors it is clear that these are not a wind spikes occurred due to instrumental problem, since the speed of wind is increasing from 6m/s to 27.10m/s and 27.90m/s gradually. Therefore, these are not errors because these have taken place due to a storm condition. These storms should be considered in designing the wind station to withstand the maximum wind speeds.

The data plot for year 1988 is as shown in figure.30

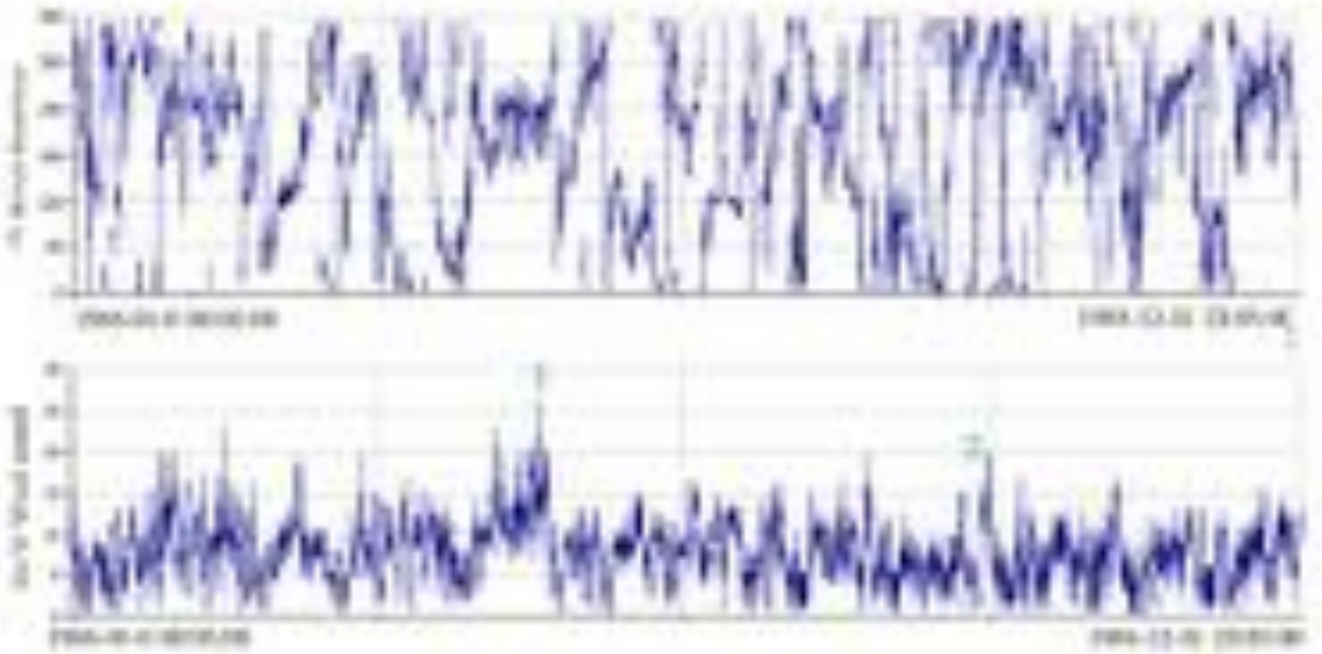


Fig. 30 Measured wind speed and direction data. Year 1988

In year 1988 there are very less errors and generally its accuracy is acceptable. Even though it is needed to observe the uncommon patterns or spikes in the data and justify its effects on wind profile.

On 1988-05-19 at 17:53:45 there has been a wind speed increment up to 26.00m/s as shown in below figure 31.

Fig. 31 wind speed increment on 1988-05-19

Thus, it is clear that this increment is gradually increasing from 10m/s and it's not a sudden spike due to instrumental error. Therefore, this is not an error and it should be considered in wind profile analyzing and designing the wind power station. On

1988-09-23 from 17:51:33 to 20:03:42 the wind speed and direction measurements were not recorded as mentioned in figure 32, and this error should not be included in the wind profile analysis.

Fig. 32 wind speed and direction missing data series on 1988-09-23

The data plot for year 1989 is as shown in figure 33

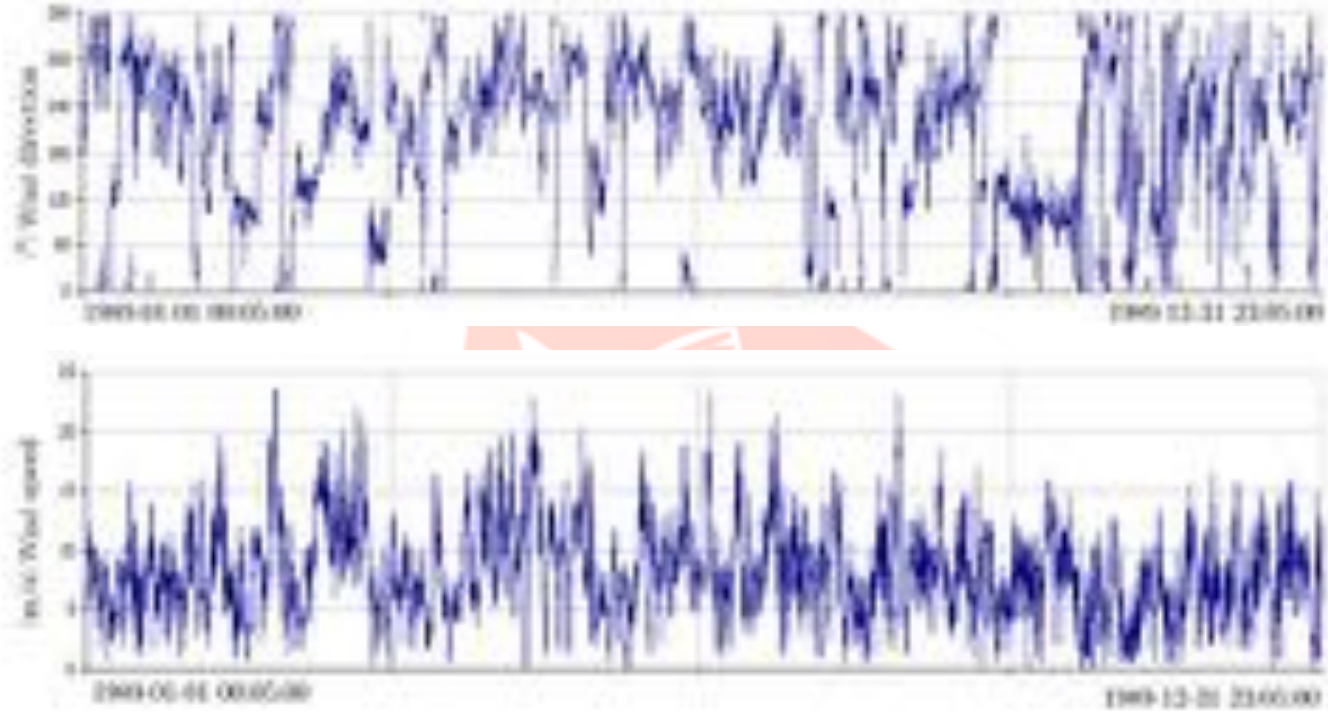


Fig. 33 wind direction and speed measurement data. Year 1989

The year 1989 has no significant error in the whole year and thus it has no any improvement needed and can be directly taken to the wind profile analysis process. The data plot for year 1990 is as shown in figure 34.

Fig. 34 wind direction and speed measurement data. Year 1990

According to the measured data, it is not possible to consider the complete year of 1990 in the wind profile analysis, since there is no observed data form 1990-01-30 (03:35:35) until end of the year. Therefore, year 1990 can be neglected from the WAsP climate analysis.

With refer to all wind measurement data collections and error eliminations, it is then created the complete wind profile as shown in figure 35.

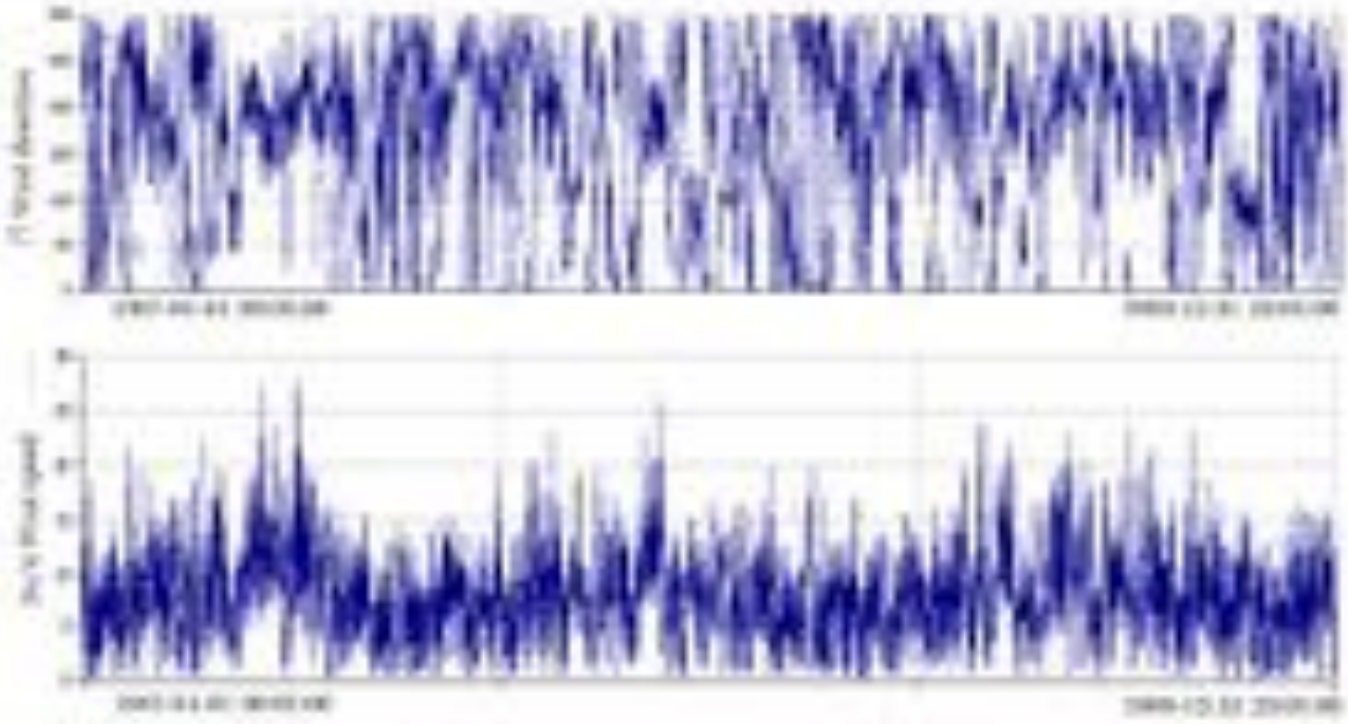


Fig. 35 complete wind direction and speed measurements. (Year 1987 to 1989)

In the completed wind measurement data set, it has 99.98% valid readings and no any missing data, constant patterns, sudden spikes and etc., The completion of data series can be summarize as below mentioned in table 02.

Table 02. Wind direction and speed data report

Selected time window	1987-01-01T00:05:00 – 1989-12-31T23:05:00
Time window length (Years)	3.00
Recordings in selection	26,287
Recording intervals	3600
Wind speed data	
Readings above upper limit	5 (0.02%)
Count of calm	12 (0.05%)
Valid readings accepted	26,282(99.98%)
Accepted value range	0.00m/s to 27.90m/s
Wind direction data	
Reading above upper limit	5 (0.02%)
Count of calm	64 (0.24%)
Valid readings accepted	26,282 (99.98%)
Accepted vale range	0.00^0 to 360.00^0
Overall Recovery Percentage	99.98%

From the completed wind speed data, it is created the mean wind speed for all months as mention in table 03 below.

Table 03. Mean wind speed data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	7.17	7.59	8.64	8.25	8.78	11.51	11.71	7.83	6.03	6.15	7.95	6.69
1988	7.57	8.10	8.09	8.06	10.85	7.59	8.74	7.47	6.69	6.53	6.95	6.95
1989	7.21	8.94	9.41	8.00	10.95	8.16	9.44	7.89	7.97	7.55	5.96	7.46
Month Avg	7.32	8.21	8.71	8.10	10.19	9.09	9.97	7.73	6.90	6.74	6.96	7.03

According to the table 03, in average, month of May, June and July can be classified as High wind season, month of February, March and April can be classified as medium wind season, and month of January, August, September, October, November and December can be classified as intermediate wind season of low wind and medium wind seasons. Low wind season can be taken below 6m/s wind speed, because many wind turbines which use in wind stations usually has a cutting wind speed of 2m/s or 3m/s.

Therefore, using WAsP climate analysis tool, it is developed the Observed Wind Climate (OWC) which will be useful to design the wind turbine station. The table 04 represent the Weibull, frequency, mean wind speed and Power density of the observed wind site. In OWC there are several strategies in Weibull fitting. Weibull fit made with preference for power density distribution and the Weibull fitting in low wind speed is less important but as the wind speed is increasing, the Weibull should be fitted with the high wind regions.

Table 04. Weibull, mean wind speed and power density in the OWC

Sector		***Wind climate***				***Power***
Number	***Angle (degree)***	***Frequency [%]***	***Weibull -A [m/s]***	***Weibull-k***	***mean speed [m/s]***	***Power density [W/m2]***
1	*0*	*5.3*	*7.4*	*1.76*	*6.57*	*383*
2	*30*	*3.9*	*7.1*	*1.87*	*6.31*	*315*
3	*60*	*3.9*	*7*	*2.27*	*6.2*	*248*
4	*90*	*5.3*	*7.7*	*2.09*	*6.81*	*355*
5	*120*	*7.3*	*9.2*	*2.93*	*8.18*	*477*
6	*150*	*7.1*	*8.4*	*2.38*	*7.42*	*411*
7	*180*	*7.8*	*9*	*2.04*	*7.94*	*576*

8	*210*	*12.0*	*9.8*	*2.34*	*8.71*	*671*
9	*240*	*14.4*	*10.1*	*2.32*	*8.99*	*743*
10	*270*	*14.3*	*9.7*	*2.36*	*8.64*	*649*
11	*300*	*12.2*	*9.7*	*2.24*	*8.6*	*670*
12	*330*	*6.5*	*7.8*	*1.84*	*6.95*	*429*
All (fitted)			***9.1***	***2.24***	***8.10***	***560***

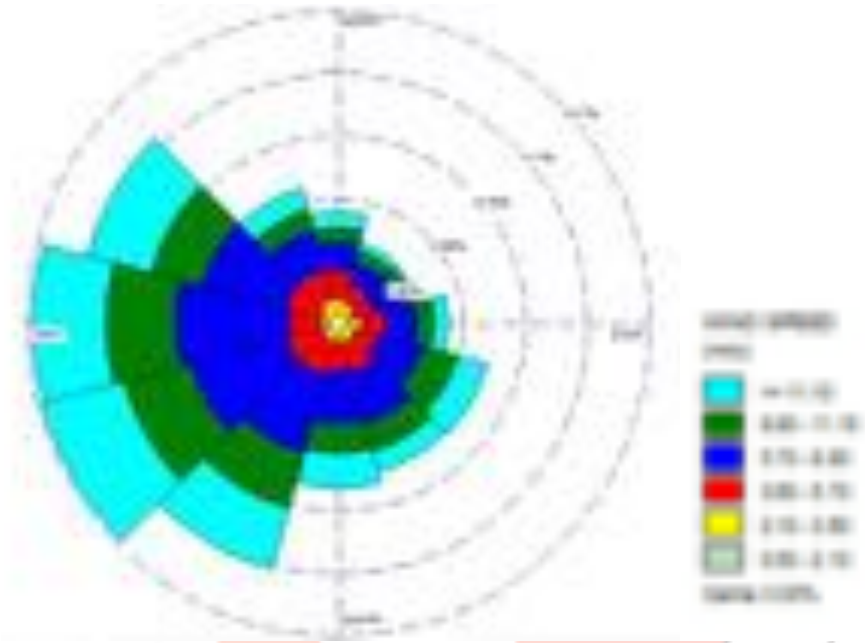


Fig. 36 wind rose distribution (360^0 is divided into 12 sections)

The above figure 36 is the wind rose which created using the actual wind measurement details on site. With refer to the design, the wind rose has divided 360 degree into 12 sections and as per the simulation results the annual prevailing wind speeds will be South-West & North-West with average wind speed of 11.0m/s. In the wind rose, if the deviation changes from 12 into 4 and 36, it will be as mentioned in below figure 37 and 38 respectively.

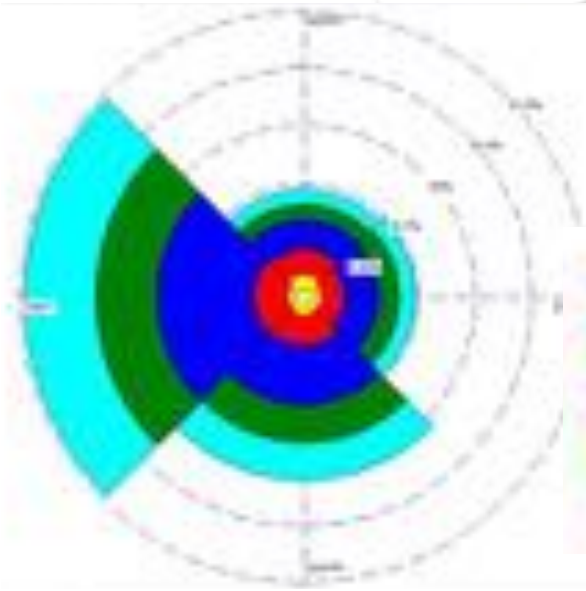


Fig. 37

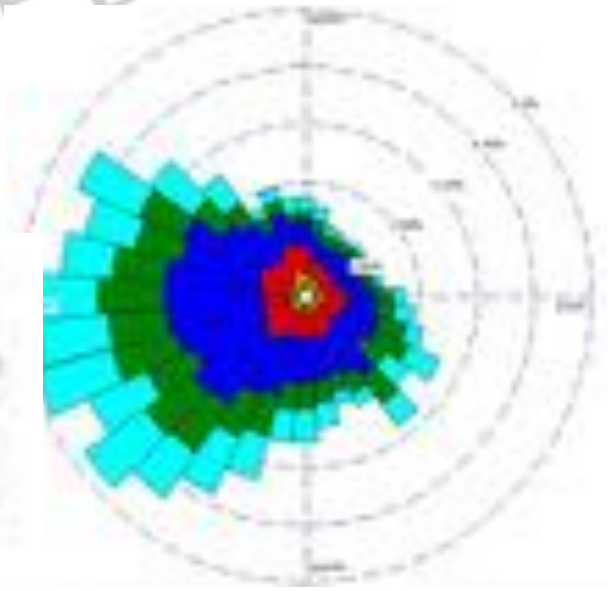


Fig.38

According to the wind rose, the wind turbine sitting in the given site should be faced North-West & South-West direction thus to get the maximum power density. The below figure 39 explains the efficient and inefficient ways of sitting wind turbines according to the wind rose.

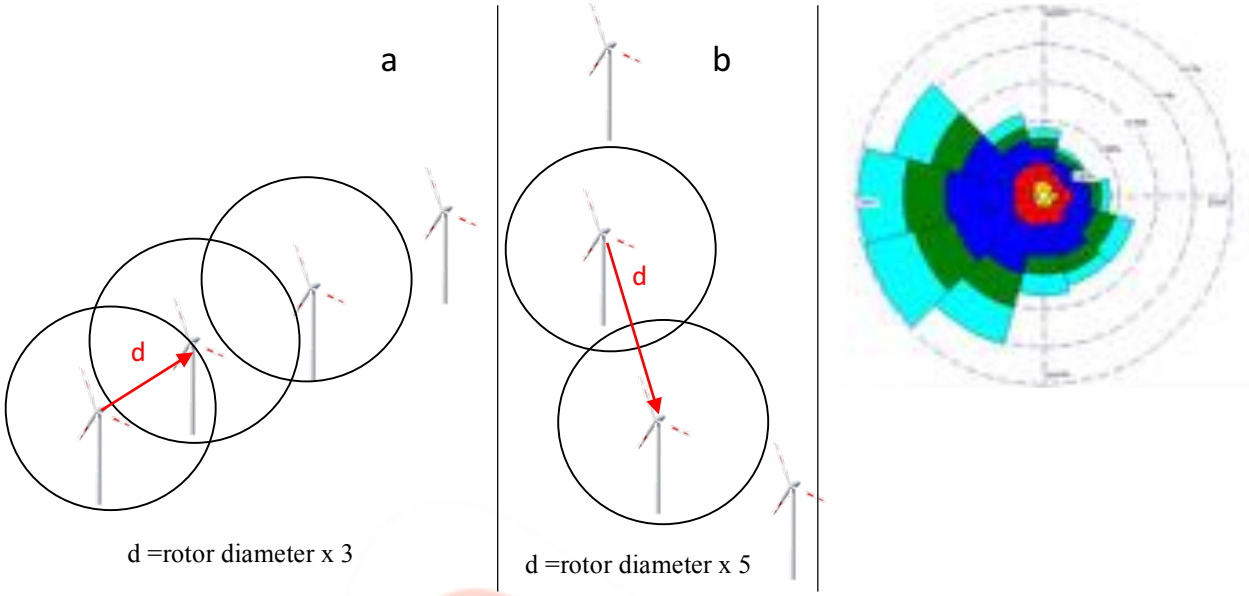


Fig. 39 a. Poor wind turbine sitting. Contains significant wake loss. b. Good wind turbine sitting. No significant wake loss, can gain more power density for generation.

According to the wind turbine sitting principles, the distance between turbine to turbine should be atleast 5 - 8 rotor diameters. This is important to avoid wake loss effect on turbines.

The below figure 40 represents the actual wind rose at site after synchronizing Google earth with wind rose.

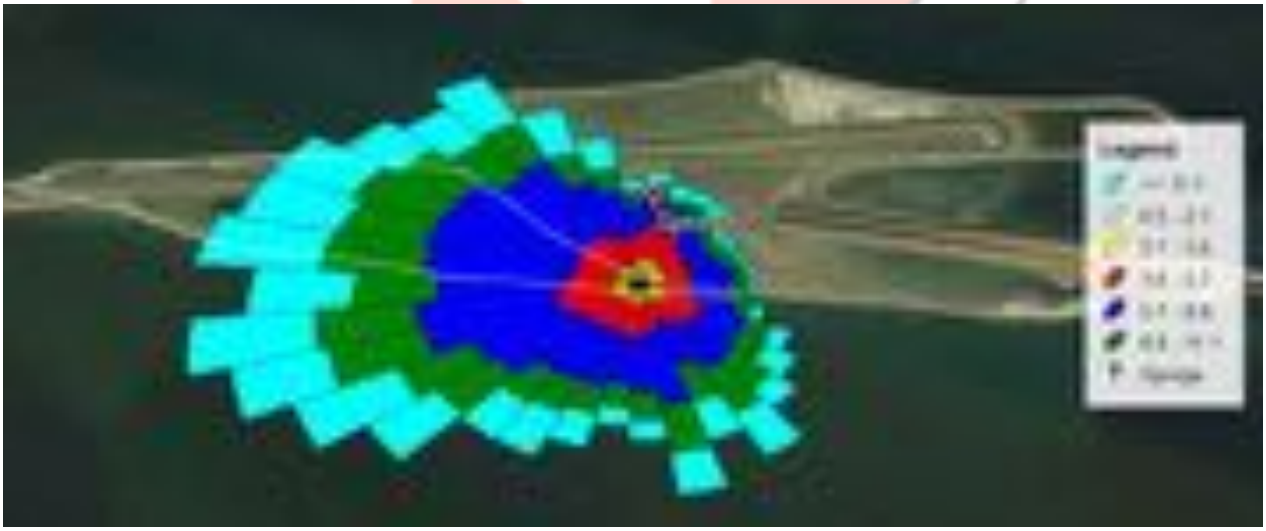


Fig. 40 Wind rose distribution at site (real distribution sync with maps)

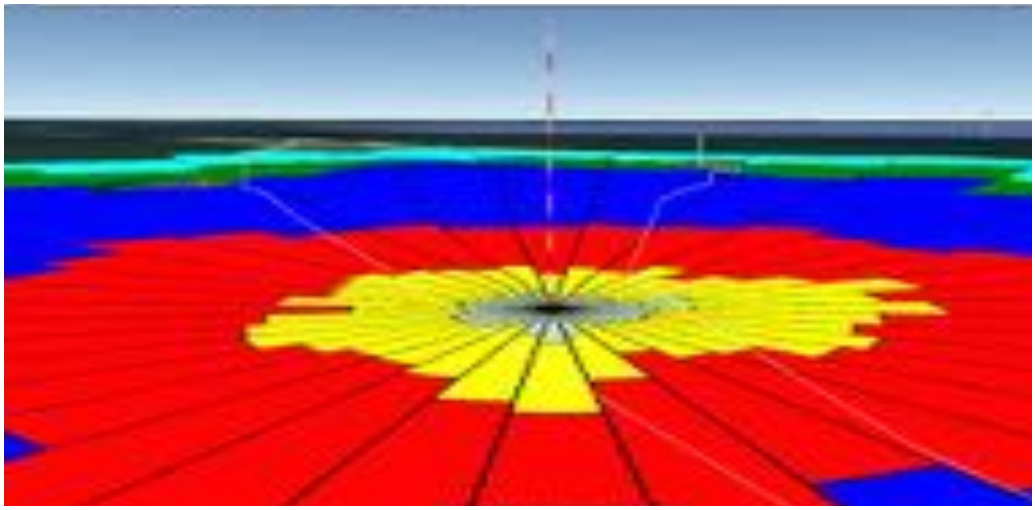


Fig.41 3D view of met station and its wind rose distribution (The figure 40 is captured facing the maximum wind rose distributed angle.)

The below graphs mentioned the Weibull shape parameter distributions in different angels of wind flows.

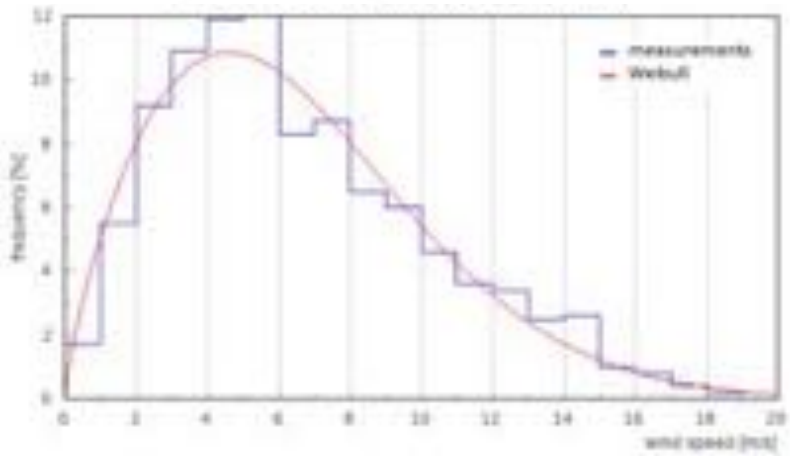


Fig.42 (0^0), k-1.76

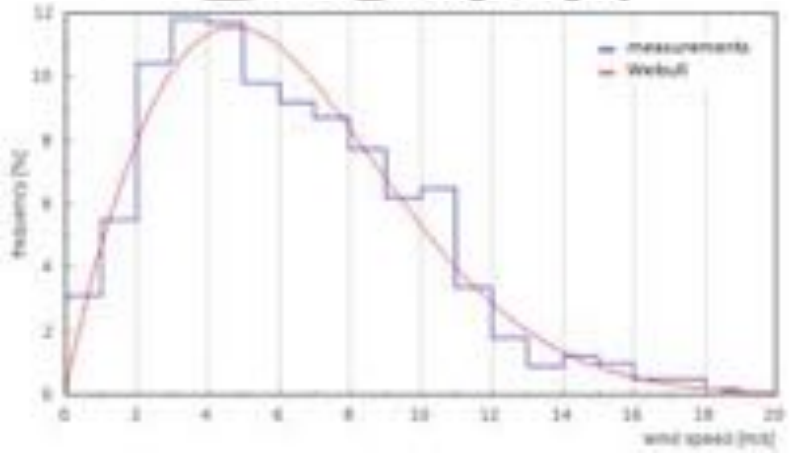


Fig.43 (30^0), k-1.87

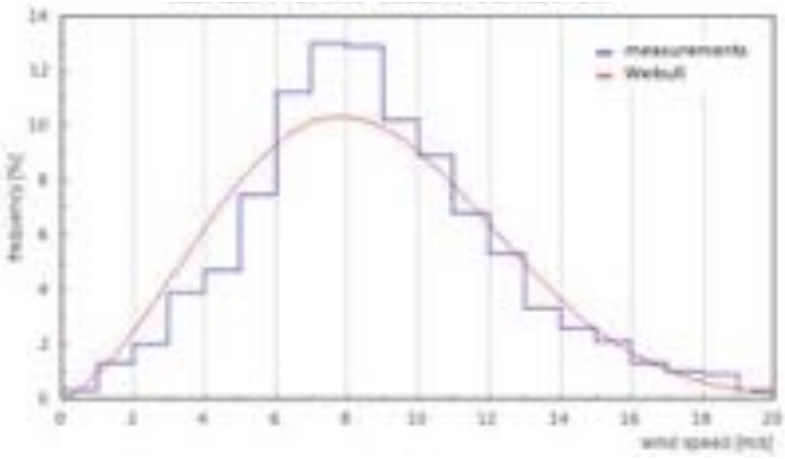


Fig. 44 (270^0), k-2.36

As per the figure 42- 44, in a specific location there can be many Weibull patterns with relative to the different directions.

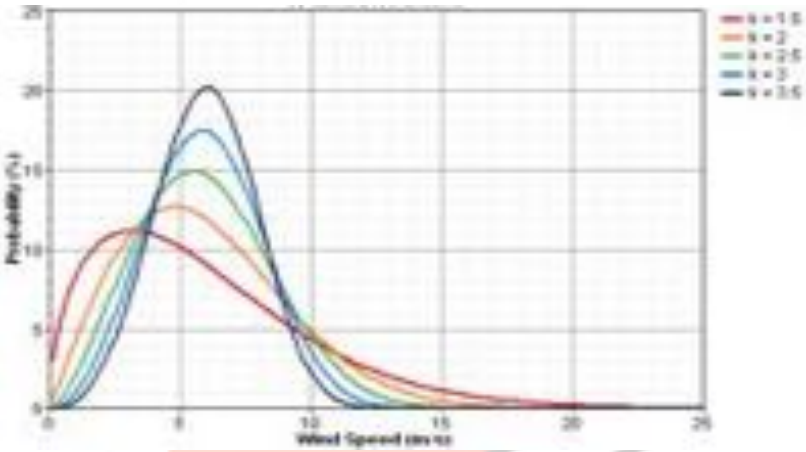


Fig. 45 Different Weibull distributions (From Homer energy Pro.3.10)

Lower k' values represent that wind speeds are broadly distributed. The gusty winds may have a Weibull-k of 1.5. When there is steady winds the Weibull-k will be higher as 3 or 4. Thus, the final Weibull distribution is the combination of all Weibulls in different directions and it is plotted as mentioned in below figure 49.

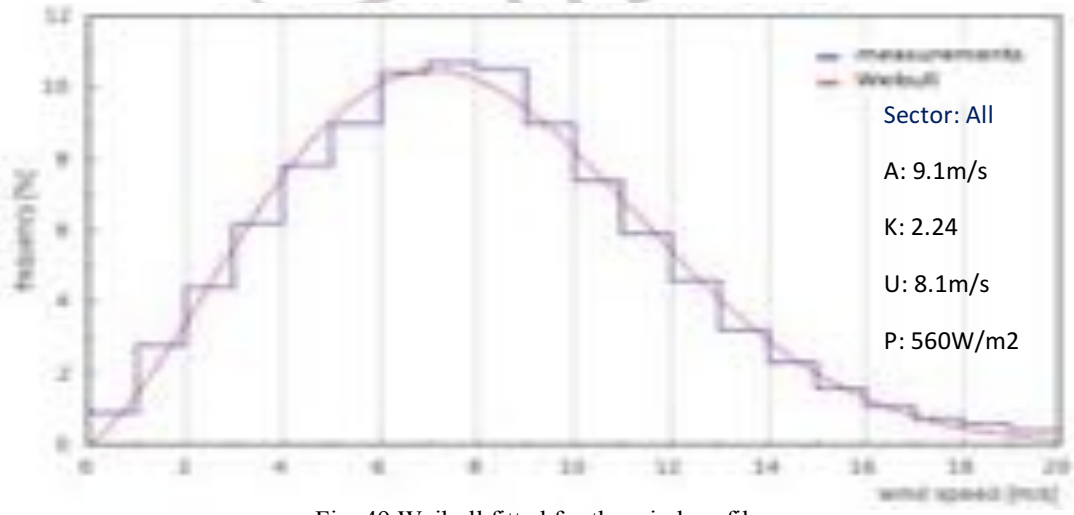


Fig. 49 Weibull fitted for the wind profile

According to the simulated Weibull graph mentioned above this has a Weibull-K' shape parameter value of 2.24 which is in the category of Rayleigh distribution and this was commonly found at most of built and commissioned wind power stations. Thus, the wind speed of 8m/s and 7m/s has the highest number of days of potential flow for power production. Wind velocities more than 19m/s are significantly small and therefore, standard wind turbines with cut-in wind speed of 4m/s and cut-off wind speed

of 25m/s can be use in this wind power station to generate power. When the K value reaches 2-3 values it is more efficient for a wind power station implementation in such the shape will be fitted more with higher wind regions which represent more power density impinging at site. The power generation of the given location can be found by the below equation, [23]

$$E = \text{Swept area of blades x wind power density x generation period x coefficient of performance} \quad (5)$$

Therefore, to calculate the value of *E,* it has taken the below wind turbine generator characteristics.

Fig. 50 Vestas V80 2MW wind turbine generator.(WaSP turbine editor software)

Rotor diameter - 80m

Default height - 67m

Coefficient Cp - 0.50

Thus, the generation in the specific location per turbine per year will be calculated by using equation 5, table 05 power density value and fig.50 turbine characteristics.

$$E = \pi * 40^2 * 560 \ {}^{W}/_{m^2} * 12 * 744 * 0.50$$

$$E = 12.565 \text{ GWh/per year}$$

The Vestas V80 turbines can be sited as below mentioned figure 51 using 3D modeling of wind turbines.

Fig. 51 3D simulation of Vestas V80 wind turbine at site.

When sitting the turbines, it was kept the distance between turbine to turbine more than 3 rotor diameters to avoid wake losses.

IV. CONCLUSION

The wind data measurement was observed in Sprogoe Denmark from 1987-1990. During the observation process it was visible some missing data in year 1987 and 1988 while 1990 was totally neglected the due to its high number of missing data's. Therefore, the total number of observed years was reduced up to 3 years and the recovery was 99.98%. From the WAsP climate analysis software, the Observed Wind Climate was created. From OWC, the mean power density, mean wind speed, Weibull-A and Weibull-K was simulated and results were obtained. According to the results, it was simulated the Wind Rose using WRPLOT software and Weibull fitting with Swiss Weibull maker software which was then obtained a well distributed simulation results. As per the total simulation results it represents that the OWC is suitable for a wind power station development and therefore it was used Vestas V80 wind turbine for calculate the annual energy generation, and using the 3D simulations, 6 turbines was placed on site to give a clear idea of turbine sitting in real scenario.

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