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School of Engineering and Applied Science

Department of mechanical engineering & Energies

Classification and Site assessment of wind farms according to international standards for IEC61400

By: ***RafeeqDawehar***

Supervised By: Dr. WedadEL_Osta

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Dedications

To all my love, my mother and father, my family, my teachers and friends, to all science students and researchers. Dedicating this humble work and asking my God it's interesting and beneficial.

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Nomenclature

A : designates the category for higher turbulence characteristics,

B : designates the category for meduem turbulence characteristics,

C : designates the category for lower turbulence characteristics

C_T : thrust coefficient of the wind turbines

cp : is the constant-pressure specific heat of air

E :The kinetic energy

$f(U)$: the Gumbel Probability Density Function

g : the gravitational constant

H : height

h_H : hub height

H_{ref} : reference elevation (measuring elevation)

I: the turbulence intensity

I_{ref}: is the expected value of the turbulence intensity at $15 \text{ m}/s$

I_0: ambient turbulence intensity

$I_{add,wf}$: added wind farm turbulence intensity

$I_{T,w,f}$: wind farm turbulence intensity

κ: is von Karman's constant

ln : natural logarithm (base e $= 2.7183$).

m : mass of air

n: no. of kilo moles.

s_r : distances between the units in the rows

s_f : the separation between the rows

P: is the pressure.

Po : atmospheric pressure

P/A : the power density

p_o : the pressure at state 0

$p1$ are and pressure at state 1

R: is the unit gas constant

T: the temperature

T_o: the temperature at state 0

$T1$: the temperature at state1

U : wind speed

U_{e1} : the extreme wind speed with a recurrence period of 1 year

U_{e50} : the extreme wind speed with a recurrence period of 50 years

U_H : mean wind velocity at elevation H

U_{ref} : is the reference wind speed average over 10 min.

U_*: is the friction velocity

U_{*0} is the friction velocity over the wind farm.

v is the volume of air parcel available to the rotor

v_G: is the value of the gas.

z : site elevation

Z_0 : The surface roughness length

Z_{00}: the roughness length over wind farm

α : Hellmann's exponent

β: scale parameter

μ: location parameter

ρ is the air density

σ **:** standard division.

σ_0 : the turbulent fluctuation

$\sigma_{T,wf}$: Standard deviation of wind speed fluctuations over wind farm

$\sigma_{add,wf}$: Added wind farm "ambient" turbulence

Abstract

The certification and testing of wind turbines is very important to provide assurance to all entities involved in wind energy projects, where national standards are found in Denmark, Germany and the Netherlands. The International Electrotechnical Commission (IEC) has published a series of international standards. The IEC standards, which have the reference number 61400 and are entitled Wind Turbine Generator Systems, have already been adopted by several countries around the world or are used as the foundation for the development of national standards.

For wind speed classification according to IEC most estimate the average wind speed at hub height, turbulence intensity and maximum gust wind speed possible occurrence.

Can estimate the wind speed at turbine hub height measured wind speeds at different altitudes, while the turbulence intensity was estimated in three cases:

First case: when the train does not contain any buildings or trees (roughness is 0.001), and the distance between the turbines is according recommendations in IEC, or the distance between the turbines be three times of the wind turbine diameter.

second case: when the roughness length is 0.001 and the distance between the turbines is less than recommendations in IEC.

Third case: when the distance between the turbines is according recommendations in IEC but the roughness length is increased to 0.003.

where selected dernah – Libya site and type of turbine to be as example for this methodology, it’s Gamessa 80 – 2MW.

Where was classification in first and second cases in class CIII, while In the third case was in class BIII. and the highest estimated wind speed possible occurrence in Site is 71 m/s.

Chapter I :

introduction

1.1 background:

The certification and testing of wind turbines is very important to provide assurance to all entities involved in wind energy projects: wind farm operators, banks, government agencies, etc. People usually comprehend certification as the examination of companies, operators or products according to certain criteria. In the Wind Energy sector certification of products and manufacturers is a standard. The certification (of conformity) is a task done by independent institutions (or persons), which document that a result, procedure or service is in accordance with a certain standard or another certain normative document.

The most important part of the wind turbine type certification is the design assessment, which generally is executed in two steps. The first step comprehends the testing of the operation and security concepts and also the design load and load calculations. The second step of the design evaluation conformity compares the results of the first step with the relevant guidelines and standards.

In the characteristic measurements performance related characteristics of the wind turbine type is established. The type characteristics measurements comprise power performance tests, power quality tests.

The foundations of the certification are standards and normative documents. Here should be distinguished wind energy specific norms and general norms, which may also be applied to wind turbines. Besides a certification of the product and the manufacturer there is sometimes an additional project specific test, especially when the local conditions are not covered by the general certification scheme.

The specific wind turbine standards used to perform these evaluations may be of international, regional or national levels. National standards are found in Denmark, Germany and the Netherlands. The International Electrotechnical Commission (IEC) has published a series of international standards. The IEC standards, which have the reference number 61400 and are entitled Wind Turbine Generator Systems, have already been adopted by several countries around the world or are used as the foundation for the development of national standards.

A first step in the development of a wind farm is to identify land with sufficient wind to support a commercial project. This calls for a series of studies, one of which is the wind-study assessment that looks at historical wind data. There may be a meteorological in the area that has accumulated sufficient information. Study teams might also look at weather archives and model-out that data to find what a potential wind farm could produce.

Various conditions of the specific site have to be evaluated according to environmental conditions which include: wind speed, standard deviation, pressure and temperature (these parameters must be taken as average values during duration of 10 minutes). The wind conditions shall be assessed from monitoring measurements made on the site by long-term records from a nearby meteorological station are recommended. Where appropriate, the site conditions shall be correlated with long-term data from local meteorological stations. The monitoring period shall be sufficient to obtain a minimum of one year of reliable data where seasonal variations contribute significantly to the wind conditions. The monitoring period should include these effects.

Classification and site assessment of wind farm depend on good analysis of wind flow, which takes into account the topography and the roughness level of the surrounding land.

The estimation of wind speed needed for the site assessment at different heights is part of information. needed for the site assessment usually the 1/7th wind power law is used. The best and economical way is to make wind speed measurements at two or three heights for a period of at least one year and then the wind shear coefficient could be calculated using measured values. This wind shear coefficient usually used with confidence to estimate the wind speed at hub height.

1.2 the factors of the wind farm siting:

The wind resource is the most obvious factor to concentrate on when choosing a wind farm location, also there are another important factors: The size, availability, reliability, warranty, proximity of operation and maintenance teams and roads.

the study conducted on the Dernah site in eastern Libya (Figure 1-1) shows Dernah site in Libya map.

(Figure 1-1) Dernah site in Libya map.

There are a number of major companies of wind turbines manufacture, they can construction wind farms under IEC standards, among them: GE Energy, Gamessa, Siemens, Enercon, Vestas.

1.3 The objective of project:

The objective of this project is to perform a site assessment of Wind Farm according to IEC standards and estimate the power density in that site by using actual data.

Chapter II:

Background of IEC standard and Literature review:

2.1 introduction:

The IEC 61400 specifies essential design requirements to ensure the engineering integrity of wind turbines. Its purpose is to provide an appropriate level of protection against damage from all hazards during the planned lifetime.

2.2 Background of IEC standard:

The preparation of national and international standards containing rules for the design of wind turbines began in the 1980s. The first publication was a set of regulations for certification drawn up by Germanischer Lloyd in 1986. These initial rules were subsequently refined as the state of knowledge grew, leading to the publication of the Regulation for the Certification of Wind Energy Conversion Systems by Germanischer Lloyd in 1993. This was further amended by supplements issued in 1994 and 1998. Meanwhile national standards were published in The Netherlands (NEN 6096, Dutch Standard, 1988) and Denmark (DS 472, Danish Standard, 1992)[10].

The IEC began work on the first international standard in 1988, leading to the publication of IEC 1400-1 Wind turbine generator systems - Part 1 Safety Requirements in 1994 (Second Edition IEC, 1997). A revised edition containing some significant changes appeared in 1999, bearing the new number IEC 61400-1, and then came (third edition , 2005) [16].

The IEC provides standards for all kinds of electrical equipment, and among these is the IEC 61400-1 standard for wind turbine safety. The approach is first to classify turbines into well-defined turbine types and then, for specific projects, to verify that site-specific conditions are within the limits of the relevant turbine type [10].

IEC 61400-1 Wind turbine generator systems - Part 1 Safety Requirements identifies four different classes of wind turbines to suit different sites wind conditions, with increasing class designation number corresponding to reducing wind speed. The reference wind is defined as the 10 min mean wind speed at hub-height with a 50 year return period.

IEC gives the opportunity to choose class appropriate by analyzing data obtained from the selected site and specifications of the type of turbine to be installed at that location. That is by finding out the value of turbulence intensity and the average annual wind speed at the site.

The Choice of class appropriate for the site allows the user to choose the best type of turbine to the site which is suitable for the production of more energy as possible, and also gives guarantees for the safety of the turbine.
The external conditions to be considered for the design are dependent on the intended site or site type for a wind turbine installation. Wind turbine classes are defined in terms of wind speed and turbulence parameters. The intention of classes is to cover most applications. The values of wind speed and turbulence parameters are intended to represent many different sites and do not give a precise representation of any specific site. The wind turbine classification offers a range of robustness clearly defined in terms of the wind speed and turbulence parameters.

The intention of the standard is to produce design loads which cover a variety of sites. It is recommended that the wind conditions at the site shall be assessed according to the basic parameters, this is mean wind speed, reference wind speed and characteristical value of the turbulence intensity. Further the wake effects of neighbouring turbines has to be considered [17].

2.3 Literature review:

StenTronæsFrandsen, 2007.

The model aims specifically at fatigue loading of operating wind turbines in wind turbine clusters. The model integrates load situations with ambient turbulence intensity and load situations under wake conditions to give the effective turbulence intensity, eventually model was developed in an attempt to fill out an empty space in national and international standards by accounting for increased loading caused by the wakes of neighbouring wind turbines in wind farms. It has been demonstrated that the model encompasses sufficient details to adequately reflect the flow environment of the wind farm. The model is composed of sub-models derived from experimental evidence and theoretical considerations[15].

Morten Nielsen et al

discussed the calculations needed for the IEC site assessment, and the developmeant the wake model irregular turbine arrays and includes the effect of wind-sector management. The authors used WAsP and WAsP Engineering. results and implement of the additional wake calculations in a new program called Windfarm Assessment Tool (WAT). WAsPEngineringprodects and neutral stability turbulence intensity, where as IEC61400-1 (3rd edation) asks for 90% percented of all turbulence situations. the authors are trying to handle this lack of information and investigating this problem with further work[10].

Arne wessel, Joachimpeinke, Bernhard lange, 2004.

The aim of the new model is to estimate the turbulence intensity at each wind turbine in a wind farm, where the model was applied to calculate the rotor averaged turbulence intensity for the 20 turbines at Middelgrunden wind farm. The results were compared with the turbulence intensities derived by Jørgensen from measured power fluctuations.

This model shows an overestimation of the turbulence intensities inside Middelgrunden wind farm. The method from Jøergensen to derive the turbulence intensity from the standard deviation of power measurement might have the disadvantage that only turbulent structures in the size of the rotor diameter have influence on these power fluctuations. If the size of the turbulent structures is decreasing in multiple wakes, the derived turbulence intensities would be too low[22].

ShafiqurRehman, Naif M. Al-Abbadi

The study aims to get the frequency distribution and the wind power output from hypothetical wind farm of 60MW installed capacity assumed to be developed using 100, 60 and 30 wind turbines of 600, 1000 and 2000kW rated power from DeWind. By using measured data of air temperature, surface pressure, mean wind speed and standard deviation. They are estimated that the value of wind shear coefficient as 0.255, the wind turbines with cut-in speed of 4 m/s can produce energy for 74% of the time at a hub-height of 40 m and 83% of the times with a hub-height of 100 m[24].

StenFrandsen and Peter Hauge Madsn

presented a model for the impact of fatigue loading of increased turbulence in wind turbine arrays. The spatially averaged component termed "ambient" or average wind farm turbulence is an important component of the fatigue model. The model is part of a general model for turbulent fatigue loading inside wind turbine clusters. The model is based on the general concept of turbulent boundary layer flow[11].

StenFrandsen and Morten L. Thøgersen

Presented a study for an offshore application of a fatigue model for wind turbines operating partly in ambient turbulence and partly wakes. In order limit the number of aeroelelastic calculations in design verification, it is necessary to reduce the measured distribution of turbulence intensities into specific design turbulence. In this study, the observation that the fatigue loading is proportional to the turbulence is used. Thus, turbulence is used as a primary design parameter, substantially describing the fatigue effects. The design turbulence is defined as the turbulence that gives an equal amount of fatigue damage as the combination of true distribution of ambient turbulence and turbulence generated from wake effects. The single most important parameter responsible for the increase in fatigue loading is very short distances between turbines[25].

Fawzi A.L. Jowder

presented the hourly measured wind speed data for years 2003–2005 at 10 m, 30 m and 60 m height for Kingdom of Bahrain have been statically analyzed to determine the potential of wind power generation. Extrapolation of the 10 m data, using the Power Law, has been used to determine the wind data at heights of 30 m and 60 m. Weibull distribution parameters have been estimated and compared annually and on monthly bases using two methods;

the graphical method and the approximated method, which depends on the standard deviation and average wind speed[26].

Chapter III:
Methodology

3.1 Introduction:

Wind turbines are subjected to environmental and electrical conditions that may affect their loading, durability and operation. To ensure the appropriate level of safety and reliability, environmental (normal and extreme categories) and electrical parameters shall be taken into account in the design.

The modern wind turbines of today are efficient and capable of producing more power as the height of the turbine rotor increases. Wind speed increases with height and hence the power output from the wind turbines. Therefore, for accurate assessment of wind power potential at a site, one should have precise knowledge of wind speed at different heights. This can be achieved either by measuring wind speed at the hub height of interest or by estimating it using 1/7th wind power law. The best and economical way is to make wind speed measurements at two or three heights for a period of at least one year and then calculate the wind shear coefficient using measured values. This wind shear coefficient then can be used with confidence to estimate the wind speed at hub height and turbulence intensity in order to classify the site according to the IEC standards and then to know wind turbine class according IEC standards for this site. The other important parameter that directly affects the wind power estimates is the air density.

3.2 Wind speed variation with height:

One of the most important phenomena with respect to the utilisation of wind energy is the increase of wind speed with altitude. The friction of the moving air masses against the earth's surface slows down the wind speed from an undisturbed value at great altitude (geostrophic wind) to zero directly at ground level. Depending on the time of day and atmospheric conditions, the range up to where the wind speed is undisturbed is between 600 and 2000 m above ground level and is called the atmospheric boundary layer.

The height of the boundary layer close to the ground is called the Prandtl layer. The flow conditions in this area are dominated by the friction of the air flow against the earth's surface. The height of the Prandtl layer varies with the meteorological conditions. During the nocturnal hours, it is only 10 to 50 m thick whereas during the day, the vertical extent is as a rule between 50 and 150 m. Investigations have shown that, for example, a rotor hub height of 60 m is within the Prandtl layer for only about 30% of the annual hours whereas it is only about 7% at a hub height of 100m[2].

The wind speed is usually recorded at a height of 10 m. Changes in elevation can change the wind speed in a distance of only a few hundred meters. Hills or mountains influence the wind speed significantly. On top of a mountain or on the luff side, the wind speed can rise to become double the uninfluenced value. In contrast, the wind speed is much lower on the lee side [18].

The increase in wind speed with height can be described as the statistical mean of an assumed steady-state speed distribution. This simplification is adequate with respect to problems based on the long-term statistical mean of the wind speed, that is to say the calculation of the energy delivery of a wind turbine. Naturally, instantaneous fluctuations that can be of significance for certain problems of the strength calculation, for example of the rotor blades, are superimposed on this mean[2].

The wind speed increases with the height from ground because the wind is slowed down by the roughness of the ground. Wind generators usually have hub heights of more than 10 metres. For the estimation of the wind potential, additional wind speed measurements at other heights are necessary. However, if the type of ground cover is known, the wind speed at other heights can be calculated [18].

3.3 Wind profile:

Wind speed profiles in highly stable atmospheres are characterized by continual wind speed increase with the increase of heights (high wind shear). Wind speed profiles in unstable atmospheres result in relatively small increases of wind speed as height increases[7].

1. **Logarithmic profile:**

A conventional approach for describing the increase in wind speed with height is the logarithmic formula:

$$\boldsymbol{U_H = U_{ref}\left(\frac{ln\left(H/_{Z_0}\right)}{ln\left(Href/_{Z_0}\right)}\right)} \qquad \text{……………………..(3-1)}$$

where:

$\boldsymbol{U_H}$: mean wind velocity at elevation $H(m/s)$.

$\boldsymbol{U_{ref}}$: mean wind speed at reference elevation $Href(m/s)$.

$\boldsymbol{H}$: height (m).

$\boldsymbol{Href}$: reference elevation (measuring elevation) (m).

$\boldsymbol{ln}$: naturallogarithm (base $\boldsymbol{e = 2.7183}$).

$\boldsymbol{Z_0}$:The surface roughness length, It depends on both the size and the spacing of roughness elements such as grass, crops, buildings, etc[2] .

The integration is from the lower limit of $\boldsymbol{Z_0}$instead of **0** because natural surfaces are never uniform and smooth. Table (3-1) gives an example of surface roughness lengths for various terrain types[6].

Table (3-1) surface roughness lengths for various terrain types[2]:

Types of terrain surfaces	Z_0 (m)
City Forest.	1.00
Suburbs.	0.50
Built-up terrain.	0.30
Many trees and/or bushes.	0.20
Agricultural terrain with a closed appearance.	0.10

Agricultural terrain with an open appearance.	0.05
Agricultural terrain with very few buildings, trees, etc.	0.03
Airports with buildings and trees.	
Airports, runway Meadow.	0.01
Bare earth (smooth).	$5.\ 10^{-3}$
Snow surfaces (smooth growth).	10^{-3}
Sand surfaces (smooth) .	3.10^{-3}
Water surfaces (lakes, fjords and the sea).	10^{-4}

2. Power law profile:

The power law represents a simple model for the vertical wind speed profile. Its basic form is:

$$\frac{U_H}{U_{H_{ref}}} = \left(\frac{H}{H_{ref}}\right)^{\alpha} \qquad \text{……………………….(3-2)}$$

Where:

$\boldsymbol{\alpha}$: Hellmann's exponent (wind shear coefficient)[4].

The early work of ***von Karman*** showed that under a certain conditions the exponent is equal to $1/7$, indicating a correspondence between wind profiles and flow over flat plates. In practice, the exponent $\boldsymbol{\alpha}$ is a highly variable quantity.

Table (3-2) shows the effect of the exponent **(α)** on the power density **(P/A)** assuming air density $\boldsymbol{\rho} = 1.225\ kg/m3$.

Table (3-2): The effect of ($\boldsymbol{\alpha}$) on power density[6]:

	$\boldsymbol{\alpha} = 0.1$	$1/7$	0.3
$\boldsymbol{U}$ ($\boldsymbol{m}/s$)	5.58	5.85	6.95
$\boldsymbol{P}/\boldsymbol{A}$ ($W/m2$)	106.4	122.6	205.6
Calculations was performed for $\boldsymbol{\rho} = 1.225\ kg/m3$			

It has been found that $\boldsymbol{\alpha}$varies with different parameters such as elevation, time of day, season, nature of the terrain, wind speed, temperature, and various thermal and mechanical mixing parameters. Some researchers have developed methods for calculating $\boldsymbol{\alpha}$from the parameters in the log law. Many researchers, however, feel that these complicated approximations reduce the simplicity and applicability of the general power law and that wind energy specialists should accept the empirical nature of the power law and choose values of $\boldsymbol{\alpha}$that best fit available wind data. [6].

$$\alpha = \frac{ln\ (U/U_{ref})}{ln(H/H_{ref})}$$

3.4. Turbulence intensity of wind speed:

The most basic measure of turbulence is the turbulence intensity. It is defined by the ratio of the standard deviation of the wind speed to the mean over that same time period[9]. The length of this time period is normally no more than an hour, and by convention in wind energy engineering it is usually equal to 10 minutes:

$$\boldsymbol{I} = \frac{\boldsymbol{\sigma}}{\boldsymbol{U}} \qquad \text{………………………….(3-3)}$$

$\boldsymbol{U}$**:** wind speed.

$\boldsymbol{\sigma}$ **:** standard division.

Turbulence intensity is frequently in the range of 0.1 to 0.4[6].

Turbulence intensity is a measure of the gustiness of the wind. High turbulence is associated with increased wind turbine system wear and increased operation and maintenance (O&M) costs. At lower wind speeds, the calculated turbulence intensity is higher. However, the higher turbulence at low wind speeds is not a concern because of the low power available at those low wind speeds. Turbulence at higher wind speeds is of greater interest and concern to wind turbine manufacturers.

Turbulence analysis determines the suitable types of turbine designs for a wind energy project. Because wind turbines must withstand a variety of wind conditions, design standards have been developed by the International Electrotechnical Commission (IEC). The IEC 61400-1:20058 has two components-one for wind speed and one for turbulence-and can be seen in Table (3-3). The standard designates four different classes of wind turbines, I through IV, which are designed for varying degrees of wind resource, with Class I being very high mean wind speed and Class IV being low mean wind speed.

The standard also designates a wind turbulence classification, A through C, that describes the amount of turbulence a turbine must be designed to withstand, with A being the highest turbulence and C being the lowest. In recent years, wind turbine manufacturers have introduced designs for sites with lower wind speeds and low turbulence known as low wind speed turbines. These turbines have larger rotors, for a given generator size, and are thus capable of producing significantly more annual energy at a low wind speed site than the Class I or II or Class A or B turbines of similar generator size[12].

A further wind turbine class, class S, is defined for use when special wind or other external conditions or a special safety class are required by the designer and/or the customer. The design values for the wind turbine class ***S*** shall be chosen by the designer and specified in the design documentation.
The particular external conditions defined for classes I,II, III and IV are neither intended to cover offshore conditions nor wind conditions experienced in tropical storms such as hurricanes, cyclones and typhoons. Such conditions may require wind turbine class S design.

Table (3-3) Wind Turbine Classes according to IEC 61400-1 (3rd)[5]:

Wind turbine class		I	II	III	IV	S
U_{ref}	**(m/s)**	50	42.5	37.5	30	Values specified by the designer
A	I_{ref}(-)	0.16				
B	I_{ref}(-)	0.14				
C	I_{ref}(-)	0.12				

In this table, the parameter values apply at hub height and

U_{ref} : is the reference wind speed average over $10\ min$.

A : designates the category for higher turbulence characteristics,

B : designates the category for meduem turbulence characteristics,

C : designates the category for lower turbulence characteristics and

I_{ref}: is the expected value of the turbulence intensity at $15\ m/s$[5].

The mean turbulence intensity is the mean value of all of the turbulence intensity data at a particular wind speed.

Table (3-3) displays design wind speed and mean turbulence intensity ratings for the different wind turbine design classes [12].

3.4.1 Vertical shear and its relation to turbulence:

For the thermally neutrally stratified planetary boundary layer in plain horizontal terrain with height-independent shear stress and with the scale of turbulence proportional to height. It is found that the vertical wind speed profile is well modelled as being logarithmic,

$$\frac{U}{U_*} = \frac{1}{\boldsymbol{\kappa}} ln\ (\frac{Z}{Z_0})$$

From this equation we can find the friction velocity U_*as:

$$U_* = \frac{\kappa\ U}{ln\ (Z/Z_0)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3\text{-}4)$$

Where:

κ: is von Karman's constant which is approximately equal to ***0.4***, Experimentally.

Z : is height above ground.

U_*: is the friction velocity[1].

The expression of equation (3-4) was adapted by the Danish standard for loading of civil engineering structures, DS 410 (1998), and the standard for design of wind turbine structures, DS 472 (2001).

Like the friction velocity, the standard deviation of turbulent wind speed fluctuations may deviate substantially from Equation (3-4), under stable and unstable stratification of the atmosphere. In particular under offshore conditions the temperature difference between air and water may become large and if so the thermal effects influence the magnitude of turbulence and vertical shear significantly. For increasingly taller wind turbines, such effects may have to be included explicitly in environmental basis for structural design.

For extreme loading, under extreme wind conditions, it is of little consequence whether non-neutral stratification is taken into account[14].

3.4.2 Ambient Turbulence within the Wind Farm:

For the planning of wind farms, knowledge of the turbulence intensity level at the wind turbines site is important for the stability. as well as for load calculations. A wide range of approaches have been developed to calculate turbulence intensities behind wind turbines[22].

For large wind farms it is necessary to re-consider the level of "ambient" turbulence intensity [14]. One or two rows of wind turbines away from the edge of the wind farm, when there is no a wind turbine immediately upwind, turbulence may be expected to be identical to the free-flow turbulence. Further into the interior of the wind farm – the distance being depending on the density of wind turbines. No wind direction offers a flow that is unaffected by wind turbine wakes. Still, at any given point of observation, the standard deviation of turbulent wind speed fluctuations may be described as composed of fluctuations not caused by a specific turbine, and fluctuations caused by a well-defined wake, generated by a wind turbine immediately upwind[11,14].In the wind farm, the mean wind speed will be reduced relative to the ambient wind speed [14].

A model for the effect of a large wind farm on the planetary boundary layer[15] is shown in the figure (3-1).

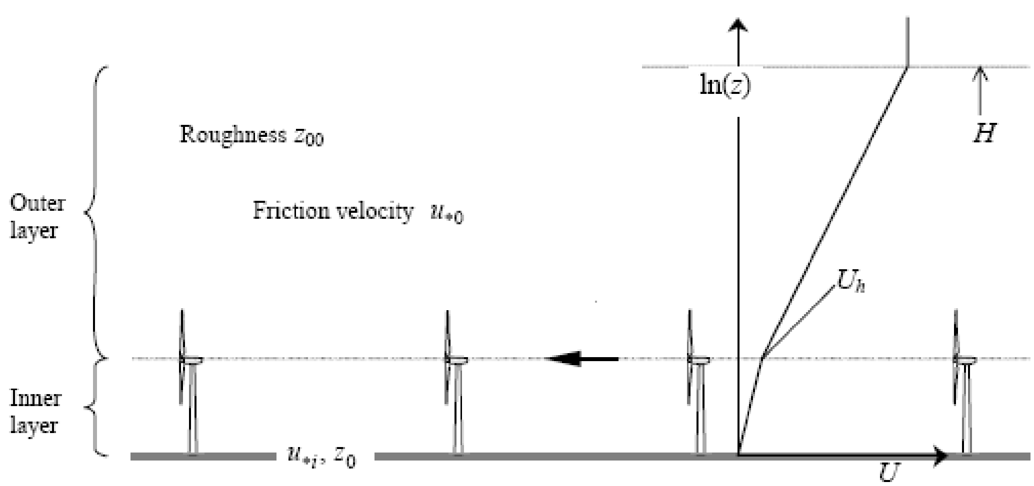


figure (3-1) Effect of a large wind farm on planetary layer

Adopting the view that the wind turbines can be considered as roughness elements, will lead to the increase of the general level of turbulence intensity, i.e there will be higher turbulence under distinct wake conditions.

In order to estimate the general decrease in mean wind speed and increase in turbulence intensity, an infinitely large wind farm is considered[11] :

$$\frac{U}{U_{*0}} = \frac{1}{\boldsymbol{\kappa}} \ ln \ (\frac{Z}{Z_{00}})$$

We can find friction velocity over the wind farm as:

$$U_{*0} = \frac{\boldsymbol{\kappa} \ U}{ln \ (^{Z}/_{Z_{00}})} \qquad \text{……..………(3-5)}$$

Where:

U_{*0} is the friction velocity over the wind farm.
Z_{00}: the roughness length over wind farm

The apparent roughness "wind farm roughness" which is composed the ground roughness and the wind turbines, may be expressed as:

$$Z_{00} = h_H \ . EXP\left(-\kappa \Big/ \sqrt{c_t + \left({}^{K}\Big/_{LN\left(\frac{h_H}{Z_0}\right)} \right)^2} \right) \qquad \text{………………(3-6)}$$

And

$$\boldsymbol{c_t} = \frac{\pi \ C_T}{8 \ S_r \ s_f}$$

Where:

$\boldsymbol{C_T}$: is the wind speed dependent thrust coefficient of the wind turbines, and $\boldsymbol{s_r}$ and $\boldsymbol{s_f}$: are distances between the units in the rows and the separation between the rows, normalized with the rotor diameter[11].

In the upwind flow or free flow – at height $\boldsymbol{h_H}$ – the turbulent fluctuation $\boldsymbol{\sigma_0}$ and turbulence intensity $\boldsymbol{I_0}$ are expressed as:

$$\sigma_0 \approx \frac{U_0}{LN(^{h_H}/_{Z_0})} = \frac{U_*}{\kappa} \qquad \text{..................(3-7)}$$

$$I_{0=} \frac{\sigma_0}{U_0} \qquad \text{..................(3-8)}$$

the turbulence over the wind farm can be estimated:

1. At the spacing in the rows perpendicular to the predominant wind direction is more than 3D then the following ambient turbulence shall be assumed:

$$\sigma_{T,wf} = \frac{U_{*0}}{\kappa} \qquad \text{..................(3-9)}$$

This expression may more generally be assumed valid some distance above the wind turbine rotor. Straining the physics, it is assumed that the expression is valid all the way down to the top position of the blades. For practical reasons, the turbulence intensity in the wind farm is defined referring to free flow wind turbine hub height wind speed ($\boldsymbol{U_0}$) as:

$$I_{T,wf} = \frac{\sigma_{T,wf}}{U_0} \qquad \text{..........................(3-10)}$$

The wind farm "ambient" turbulence may be composed of 2-components: one from terrain surface roughness and the other component stemming from the presence of the wind turbines:

$$\sigma^2{}_{T,wf} = \sigma^2{}_0 + \sigma^2{}_{add,wf} \qquad \text{....................(3-11)}$$

$$I^2{}_{T,wf} = I^2{}_0 + I^2{}_{add,wf}$$

From this equation we can find added wind farm "ambient" turbulence as:

$$I_{add,wf} = \sqrt{I_{T,wf}{}^2 - I_0{}^2} \qquad \text{......................(3-12)}$$

where:

$\boldsymbol{\sigma_{T,wf}}$ Standard deviation of wind speed fluctuations over wind farm [m/s]

$\sigma_{add,wf}$ Added wind farm “ambient” turbulence [m/s]

$I_{add,wf}$ Addedwind farm turbulence intensity[11,14].

At the spacing in the rows perpendicular to the predominant wind direction is less than 3D then the following ambient turbulence shall be assumed:

$$\sigma'_{T,wf} = \frac{1}{2}\left(\sqrt{\sigma'_{add,wf} + \sigma_0{}^2} + \sigma_0\right) \qquad \text{.....................(3.13)}$$

Where:

$$\sigma'_{add,wf} = \frac{0.36\, U_h}{1+0.2\sqrt{d_r\, d_f / C_T}} \qquad \text{.....................(3.14)}$$

$\sigma'_{T,wf}$: Standard deviation of wind speed fluctuations over wind farm when the distance between rows less than 3D [m/s].

$\sigma'_{add,wf}$: Added wind farm “ambient” turbulence when the distance between rows less than 3D [m/s].

where the turbulence intensity refers to hub height wind speed[5].

3.5. Power density:

Energy available in wind is basically the kinetic energy of large masses of air moving over the earth’s surface. Blades of the wind turbine receive this kinetic energy, which is then transformed to mechanical or electrical forms, depending on our end use. The efficiency of converting wind to other useful energy forms greatly depends on the efficiency with which the rotor interacts with the wind stream[15] .

The kinetic energy of a stream of air with mass m and moving with a velocity U is given by:

$$E = \frac{1}{2}\, m\, U^2 \qquad \text{..................(3-15)}$$

Consider a wind rotor of cross sectional area (A) exposed to this wind stream as shown in Figure (3-2). The kinetic energy of the air stream available for the turbine can be expressed as:

$E = \frac{1}{2} \rho\, v\, U^2$ ……………(3-16)

Where:

v is the volume of air parcel available to the rotor.
ρ is the air density.

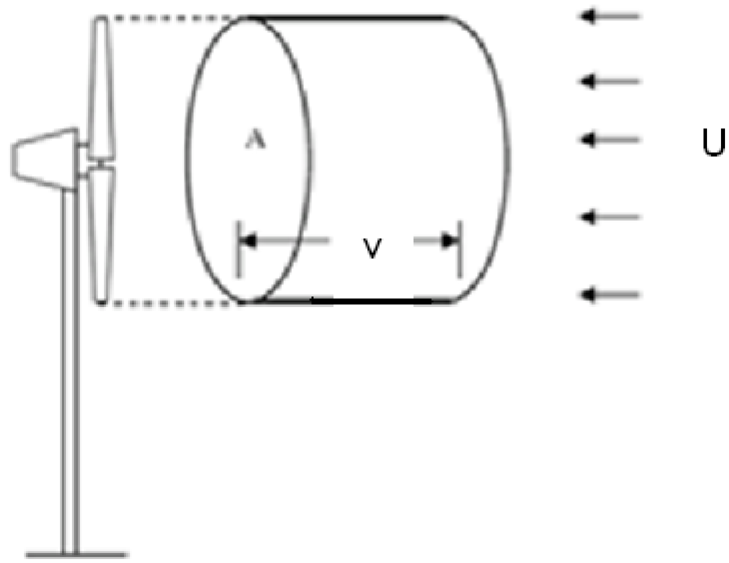


Figure (3-2)

The air parcel interacting with the rotor per unit time has a cross-sectional area equal to that of the rotor (***A***) and thickness equal to the wind velocity (***U***). Hence energy per unit time, that is power, and the power per unit area, that is power density, can be expressed as:

$P/_A = \frac{1}{2}\, \rho\,\, U^3$ ..……………….(3-17)

If could be noticed that the factors influencing the power available in the wind stream are the air density, area of the wind rotor and the wind velocity. the Effect of wind velocity is more prominent owing to its cubic relationship with power, what may appear to be a small increase in average speed yields a significant increase in available energy[12,15].

Factors like temperature, atmospheric pressure, elevation and air constituents affect the density of air. Dry air can be considered as an ideal gas. According to the ideal gas law:

$$v = \frac{n\,R\,T}{p} \qquad \text{..……………….(3-18)}$$

Where:

v_G: is the volume of the gas.

n: no. of kilo moles.

R: is the universal gas constant(287 J/kg.K).

T: the temperature (K).

P: is the pressure.

ρ: is the air density is the ratio of the mass m of one kilomole of air to its volume.

$$\rho = \frac{m}{v} \qquad \text{………………….(3-19)}$$

The volume of one kilomole varies with pressure and temperature as specified by ideal gas law. Inserting the ideal gas law into last equation, $R = 8.3145\ KJ/(\text{kmol}\cdot\text{K})$ and $m = 28.97\ Kg/\text{Kmol}$, the air density is given by[15]:

$$\rho = \frac{mp}{RT} = \frac{3.484\ p}{T}\ \text{Kg / m}^3 \qquad \text{………………...(2-20)}$$

Where:

T is ambient temperature[15].

Or could be given interns of site elevation z and temperature T as:

$$\rho = \frac{P_0}{T} e^{\left(\frac{-g\,Z}{R\,T}\right)}$$

Where:

Po the standard sea level atmospheric pressure (101,325 Pa), or the actual sea level adjusted pressure reading from a local airport.

g = the gravitational constant (9.8 m/s²).

Substituting in the numerical values for Po, R, and g, we get[23]:

$$\rho = \frac{353.049}{T} e^{\left(-0.034\frac{Z}{T}\right)} \text{Kg / m}^3$$

-Effect of temperature and pressure on air density:

A given parcel of air has a mass and is attracted to the earth by the force of gravity. For the parcel not to fall on the earth's surface, there must be an equal and opposite force directed away from the earth. This force comes from the decrease in air pressure with increasing height. The greater the density of air, the more rapidly must pressure decrease upward to hold the air at constant height against the force of gravity. Therefore, pressure decreases quickly with height at low altitudes, where density is high, and slowly at high altitudes where density is low. This balanced force condition is called hydrostatic balance or hydrostatic equilibrium.

It will be seen later that the power output of a wind turbine is proportional to the air density, which in turn is proportional to the air pressure. A given wind speed therefore produces less power from a particular turbine at higher elevations, because the air pressure is less. A wind turbine located at an elevation of $1000\,m$ above sea level will produce only about $90\,\%$ of the power it would produce at sea level, for the same wind speed and air temperature.

The temperature variation with altitude is very important to the character of the winds in the first $200\ m$ above the earth's surface, so it will be examined in some detail. We observe that Equation of (the ideal gas law) can be satisfied by pressure and temperature decreasing with altitude while the volume of one kmol (the specific volume) is increasing. Pressure and temperature are easily measured while specific volume is not. It is therefore common to use the first law of thermodynamics (which states that energy is conserved) and eliminate the volume term from Equation of (the ideal gas law). When this is done for an adiabatic process , the result is:

$$\frac{p_1}{p_0} = (\frac{T_1}{T_0})^{cp}/_R \qquad \text{.................(3-21)}$$

where $T1$ and $p1$ are the temperature and pressure at state 1, $T_o$and p_o are the temperature and pressure at state 0, R is the universal gas constant, and cp is the constant-pressure specific heat of air. The average value for the ratio R/cp in the lower atmosphere is 0.286.

by the equation (3-19) we can calculate pressure at state 1, but temperature we can calculate it by:

$$T_a(h) = T_g - R_a\ (h - h_g) \qquad \text{.................(3-22)}$$

Where $\boldsymbol{T_a(h)}$ is the temperature at elevation $\boldsymbol{h}$ m above sea level if all processes are adiabatic, $\boldsymbol{T_g}$ is the temperature at ground level $\boldsymbol{h_g}$, and $\boldsymbol{R_a}$ is the adiabatic lapse rate, $0.01C^o/m$. The quantity $h - h_g$ is the altitude above ground level.

This ideal temperature decrease is reasonably linear up to several kilometers above the earth's surface[3].

3.6 Extreme wind speed and extreme gust speed with a recurrence period of N-years:

In the wind turbine classification the extreme wind speed averaged over 10 min is used as a reference wind speed. The basis for assessment for the survival of a wind turbine is the so-called 50-year gust, the highest wind speed, averaged over 5 seconds, which is exceeded only once within a period of 50 years [2,5].

Extreme wind speeds are very high, sustained winds which will probably occur, but only rarely. Two extreme wind speeds are defined by the frequency with which they are expected to recur, the 50-year extreme wind (U_{e50}) and the 1-year extreme wind (U_{e1}). They are based on the reference wind.

Extreme coherent gust is a rapid rise in wind speed across the rotor. The IEC extreme coherent gust is assumed to have an amplitude of 15 m/ s and to be superimposed on the mean wind[6].

The design of wind turbines must allow them to withstand extremes of wind speed. Therefore the various standards also specify the extremes of wind speed which must be designed for. This includes extreme mean wind speeds as well as various types of severe gust.

Extreme conditions may be experienced with the machine operating, parked or idling with or without various types of fault or grid loss, or during a particular operation such as a shut-down event. The extreme wind conditions may be characterized by a 'return time': for example a 50 year gust is one which is so severe that it can be expected to occur on average only once every 50 years. It would be reasonable to expect a turbine to survive such a gust, provided there was no fault on the turbine.

It is always possible that the turbine happens to be shut down on account of a fault when a gust occurs. If the fault impairs the turbine's ability to cope with a gust, for example if the yaw system has failed and the turbine is parked at the wrong angle to the wind, then the turbine may have to withstand even greater loads. However, the probability of the most extreme gusts occurring at the same time as a turbine fault is very small, and so it is usual to specify that a turbine with a fault need only be designed to withstand.

For this to be valid, it is important that the faults in question are not correlated with extreme wind conditions. Grid loss is not considered to be a fault with the turbine, and is actually quite likely to be correlated with extreme wind conditions. Clearly the extreme wind speeds and gusts (both in terms of magnitude and shape) may be quite site-specific. They may differ considerably between flat coastal sites and rugged hill-tops for example.

The IEC (1999) standard, for example, specifies a 'reference wind speed' U_{ref} which as shown in table (3-3)[16].

Table (3-4)Wind turbine classes according to correlation of U_{ref} and average wind speed according to IEC (1999) standard[8]:

Class	I	II	III	IV
U_{ref} (m/s)	50	42.5	37.5	30
U_{anuale} (m/s)	10	8.5	7.5	6

For the steady extreme wind model, the extreme wind speed, U_{e50}, with a recurrence period of 50 years, and the extreme wind speed, U_{e1}, with a recurrence period of 1 year, can be computed as a function of height, H, using the simply equations[5]:

$$U_{e50}(H) = 1.4U_{ref}\left(\frac{H}{H_{hub}}\right)^{0.11} \quad \text{………………(3-23)}$$

A wind speed which is reached once annually statistically is defined as a so-called annual gust[5]:

$$U_{e1}(H) = 0.75\, U_{e50}(H) \quad \text{………………(3-24)}$$

But Gumbel distribution can be use to estimate the gust extreme of wind speed .

-Gumbel distribution:

The Gumbel distribution is a particular case of the generalized extreme value distribution (also known as the Fisher-Tippett distribution). and takes its name from Emil J. Gumbel[20].

In probability theory and statistics, the Gumbel distribution is used to model the distribution of the maximum (or the minimum) of a number of samples of various distributions. Such a distribution might be used to represent the distribution of the maximum level of values in a particular year[21].

The use of Gumbel distribution to assess the frequency of extreme events from a historic record of annual maxima, depends critically on the assumption that the distribution from which the data are a sample remains constant over time[13].

The potential applicability of the Gumbel distribution to represent the distribution of maxima relates to extreme value theory which indicates that it is likely to be useful if the distribution of the underlying sample data is of the normal or exponential type.

The Gumbel Probability Density Function is given by[20,21]:

$$f(U) = \frac{1}{\beta} . e^{-\frac{U-\mu}{\beta}} . e^{-e^{-\frac{U-\mu}{\beta}}} \qquad \text{………………(3-25)}$$

Where:

μ: location parameter

β: scale parameter

And:

$$\mu = U + \gamma\beta$$

Where: γ = 0.577216 and $\beta = \sqrt{6}\ \sigma/\pi$.

Chapter IV:

Results & discussion:

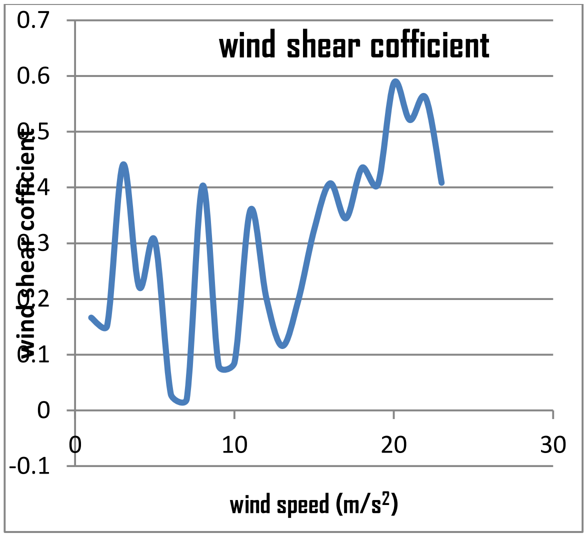
Estimation of wind characteristics is considered as the first essential step to evaluate a wind energy project based on information about all aspects of the implementation and operation of the project. It is therefore necessary to have detailed knowledge of the wind to select the suitable wind turbine for a certain zone and also to estimate its performance accurately. Various parameters need to be known , including the mean wind speed, standard deviation, pressure, temperature, variations about the mean in the short term (gusts), and variations with height. These parameters are highly site specific and can only be determined with sufficient accuracy by measurements at a particular site over a sufficiently long period.

The calculation are based on specification of wind turbine known as *Gamessa G80-2.0MW* which has a power & CT curves as shown in appendix (1). And Utilizing wind data of derrnah site, which was taken from REAOL.

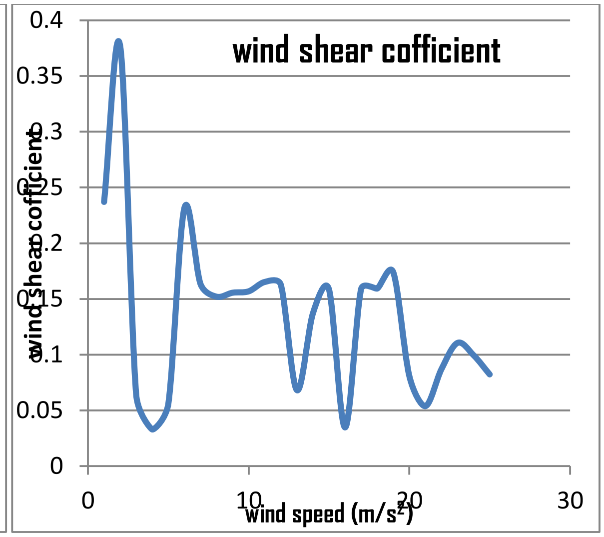
4.1 Wind shear coefficient:

Wind shear coefficient was calculated using eq.(3-2) using two heights (20m and 40m at ground level).Data of four months were taken to represent the variation of wind speed of the four seasons of the year. The results are presented in figure (4-1). The wind shear coefficient values, where we note that values ranging from 0.02 to 0.59 and 0.07 to about 0.43 in figures (4-1)a, (4-1)c respectively.

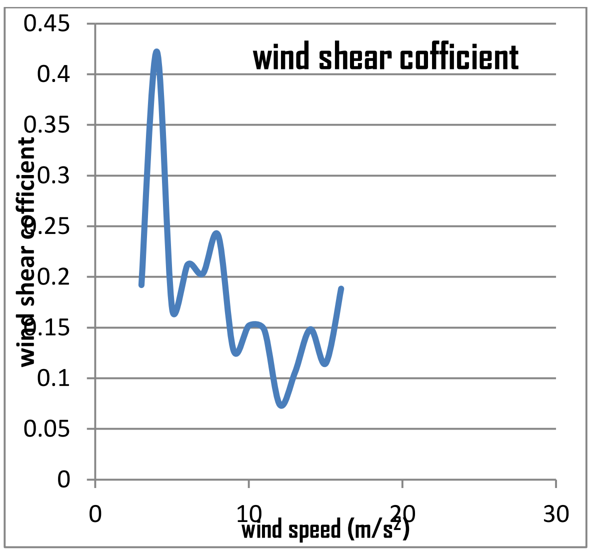
From figure (4-1) it could be natural that the variation of the wind shear ranges between 0.03 to about 0.39 and 0.04 to about 0.38, as shows in figures (4-1)c, and (4-1)d, with an average value of 0.15 while its values reaches a value of 0.59 in December (winter time).



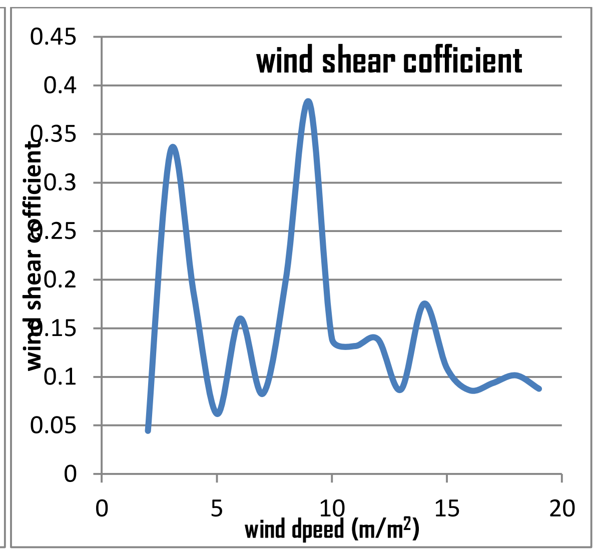
a)wind shear coefficient in December/ 2002



b) wind shear coefficient in March/2003



c) wind shear coefficient in July/2003



d) wind shear coefficient in September /2003

figure (4-1) wind shear for four months at heights 20-40m at ground level.

Figure (4-1) represent of wind shear (Hellmann's exponent) (α) for different four months according equation (3-2) by the used two heights 20m and 40m.

In figure (4-1)a represent the result for December 2002, the values of wind shear coefficient varied between 0.02 and 0.59, which for March 2003[

figure (4-1)b] the values of wind shear coefficient varied between 0.07 and 0.43.

In figure (4-1)c and (4-1)d which represent the wind shear coefficient for July and September 2003, the values of the wind shear coefficient ranged between 0.03 - 0.39 and 0.04 – 0.38 respectively.

It could be noticed the maximum value was 0.59, which was reached in December 2002 (winter time) which the average value was determined as 0.15.

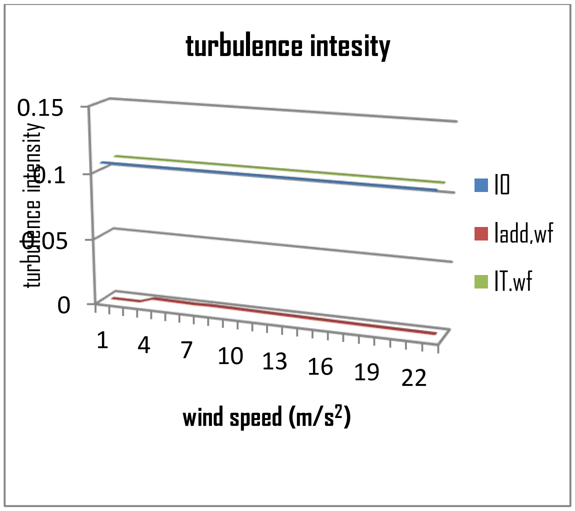
4.2 turbulence intensity:

4.2.1 turbulence intensity when the distance between the turbines is more than 3D "according recommendations the IEC" and the surface roughness length = 0.01:

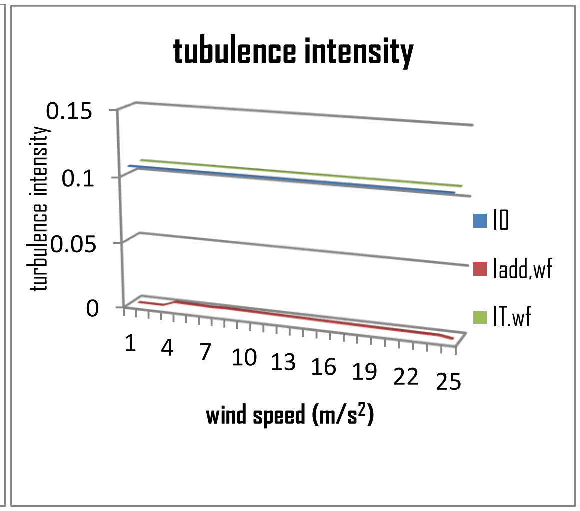
when wind speed is low we note that the value of wind farm turbulence intensity is height, that because the turbulence intensity inversely proportional with wind speed and the added turbulence intensity has height value and equal in all figures, where it has a value about 0.107843, while decreases at the increase of wind speed, until its value reaches of 0.107823 in winter and 0.107826 in summer respectively, while its value reaches 0.107820 and 0.107816 in spring and autumn. The average value is determined as 0.107821.

The results are shown in figure (4-2-1)a to (4-2-1)d.

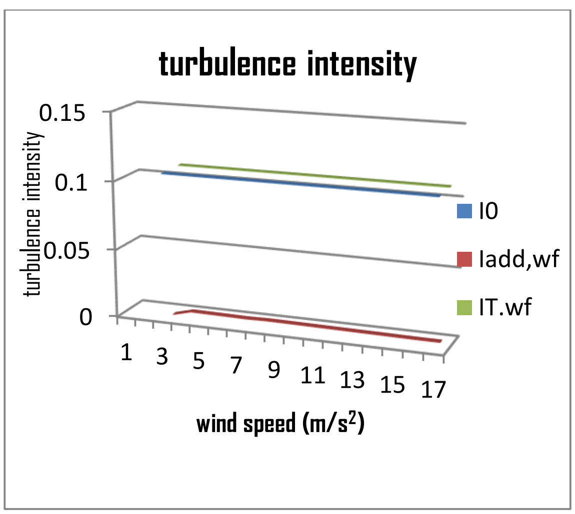
From these figures it was found that the added "ambient" wind farm turbulence were small. Therefore the wind farm turbulence intensity was close to the ambient turbulence intensity. Generally, turbulence intensity at 15 m/s was determined as 0.1078.



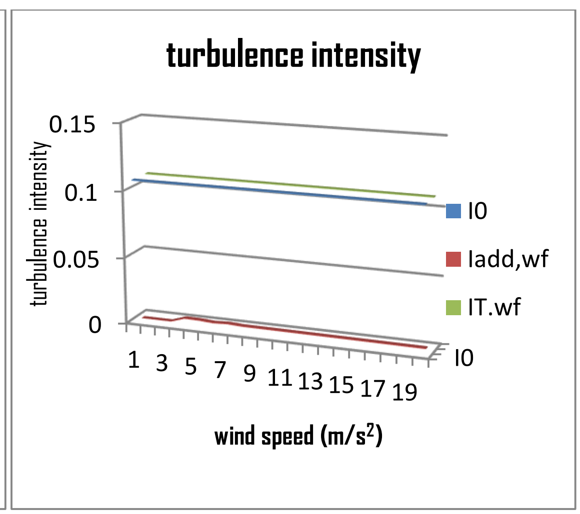
a) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in December / 2002



b) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in March / 2003



c) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in July / 2003



d) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in September /2003

figure (4-2-1) turbulence intensity, ambient wind farm turbulence and wind farm turbulence intensity for four months with s_f *=480,* s_r *= 320m and* z_0*=0.001.*

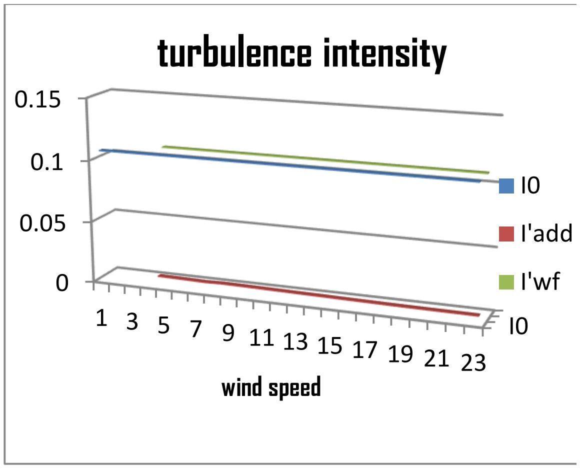
Figure (4-2-1) this curves shows comparison between ambient turbulence intensity (I_0), added "ambient" wind farm turbulence ($I_{add,w,f}$),and wind farm turbulence intensity ($I_{T,w,f}$), for four months according equation (3-8), (3-10), (3-12) respectively. with Stander deviation of wind speed fluctuations in wind farm "ambient turbulence", added wind farm "ambient" turbulence and Standard deviation of wind speed fluctuations over wind farm respectively at hub height 67m and rotor diameter 80m and d_r is 320m and d_f is 480m.

In figure (4-2-1)a which represent the results for December 2002 and March 2003, the values of added turbulence intensity ranged between 0.0036 at wind speed 4 m/s and 0.001693 at 23 m/s, in December 2002 which for March 2003 [figure (4-2-1)b] the values of added turbulence intensity varied between 0.0036 at 4 m/s and 0.001645 at 24 m/s.

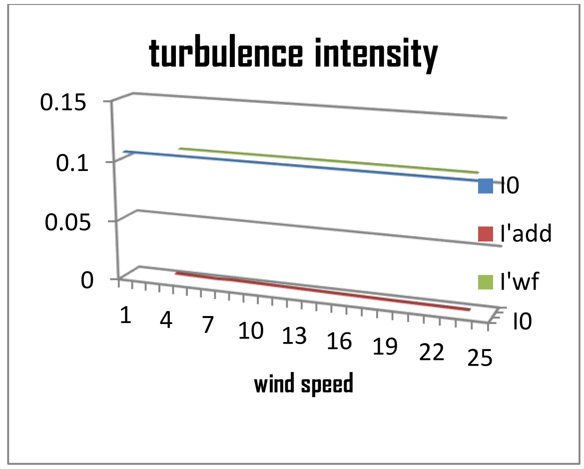
In figure (4-2-1)c which represent the results for July 2003, the values of the added turbulence intensity ranged between 0.0036 at 4 m/s and 0.0023 at 16.23 m/s which for September 2003 in figure (4-2-1)d the values varied between 0.0036 at wind speed 4 m/s and 0.0019 at 20 m/s.

4.2.2 turbulence intensity when the distance between the turbines is less than 3D and the surface roughness length =0.01.

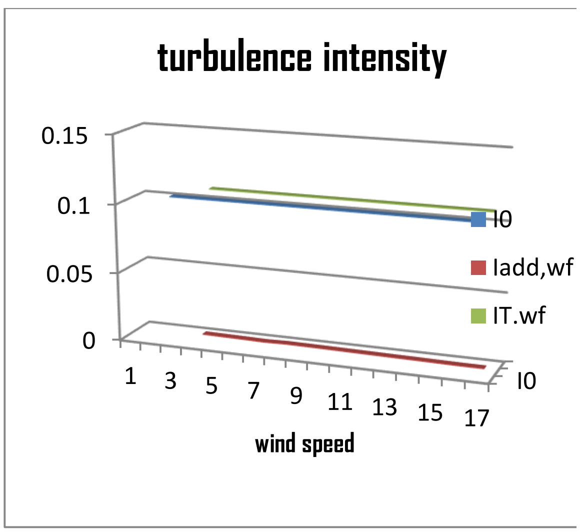
In this case the added turbulence intensity has value 0.00444 at 4 m/s, while decreases at increases the wind speed, until its value reaches of 0.00209 in winter and 0.00281 In summer, while its value reaches 0.00203and 0.00232 in spring and autumn, Generally, the turbulence intensity at 15 m/s was 0.1078.



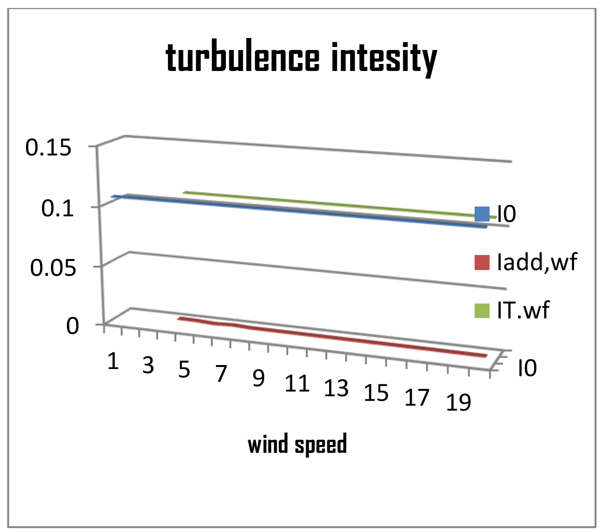
a) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in December / 2002



b) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in March / 2003



c) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in July / 2003



d) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in September /2003

figure (4-2-2) turbulence intensity, ambient wind farm turbulence and wind farm turbulence intensity for four months with s_f =160, s_r = 80m and z_0=0.001

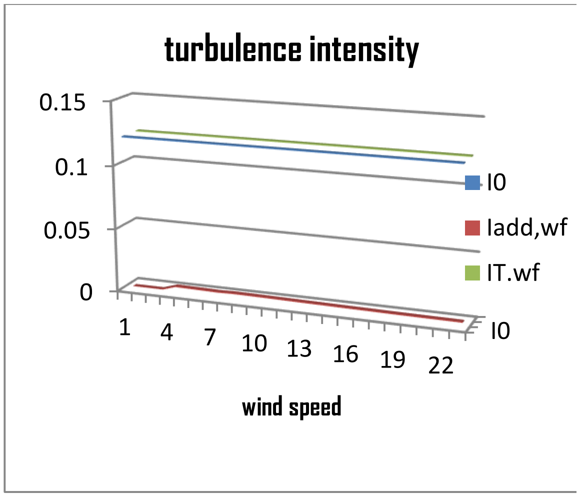
Figure (4-2-2) this curves shows comparison between ambient turbulence intensity (I_0), added "ambient" wind farm turbulence ($I_{add,w,f}$),and wind farm turbulence intensity ($I_{T,w,f}$), for four months according equation (3-8), (3-13), (3-14) respectively. with Stander deviation of wind speed fluctuations in wind farm "ambient turbulence", added wind farm "ambient" turbulence and Standard deviation of wind speed fluctuations over wind farm respectively at hub height 67m and rotor diameter 80m and d_r is 80m , d_f is 160m and Z_0= 0.001.

In figure (4-2-2)a which represent the results for December 2002, the values of added turbulence intensity ranged between 0.0044 at wind speed 4 m/s and 0.00209 at 23 m/s, in December 2002 which for March 2003 [figure (4-2-2)b] the values of added turbulence intensity varied between 0.0044 at 4 m/s and 0.00204 at 24 m/s.

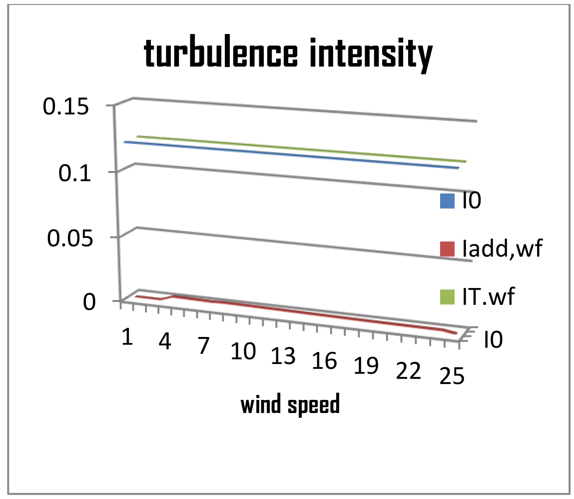
In figure (4-2-2)c which represent the results for July 2003, the values of the added turbulence intensity ranged between 0.0044 at 4 m/s and 0.0028 at 16.23 m/s which for September 2003 in figure (4-2-2)d the values varied between 0.0044 at wind speed 4 m/s and 0.0023 at 20 m/s.

4.2.3 turbulence intensity when the distance between the turbines is more than 3D and the surface roughness length =0.03.

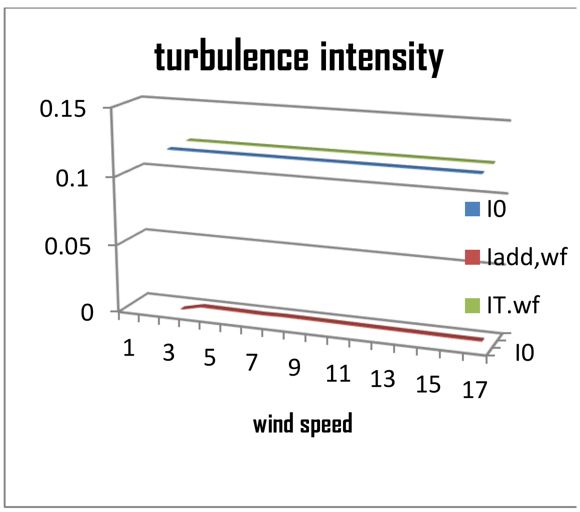
Here the surface roughness length is changed, the ambient turbulence intensity has value 0.12226, while the added turbulence intensity has value 0.00358 at 4 m/s, while decreases at increases the wind speed, until its value reaches of(0.00167), (0.00163), (0.00186) in winter, spring and autumn respectively, while its value reaches0.00228 In summer, Generally, the turbulence intensity at 15 m/s was 0.12228.



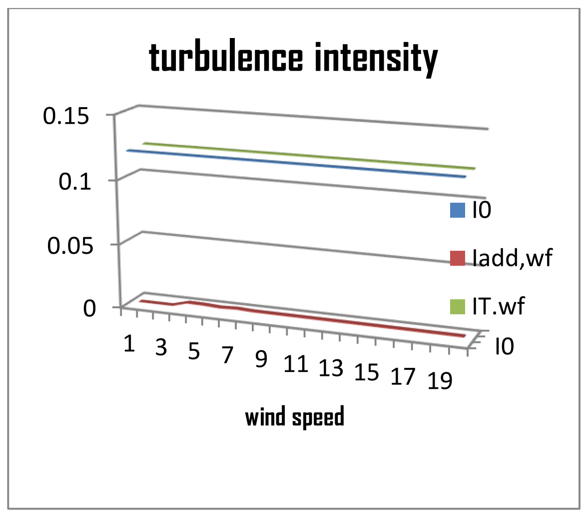
a) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in December / 2002



b) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in March / 2003



c) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in July / 2003



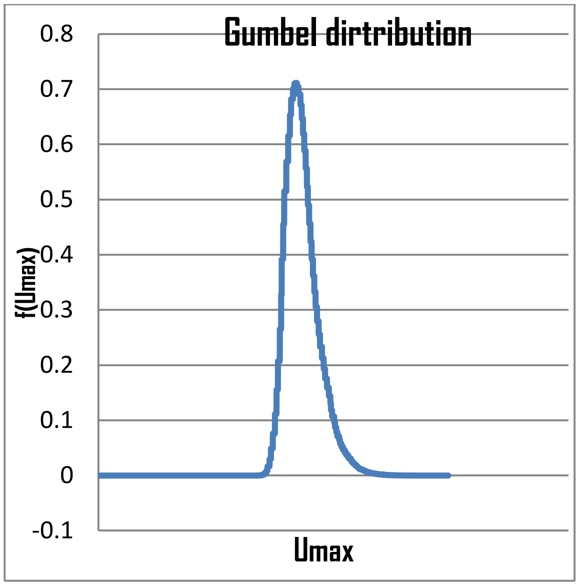
d) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in September /2003

figure (4-2-3) turbulence intensity, ambient wind farm turbulence and wind farm turbulence intensity for four months with s_f =480, s_r = 320m and z_0=0.003.

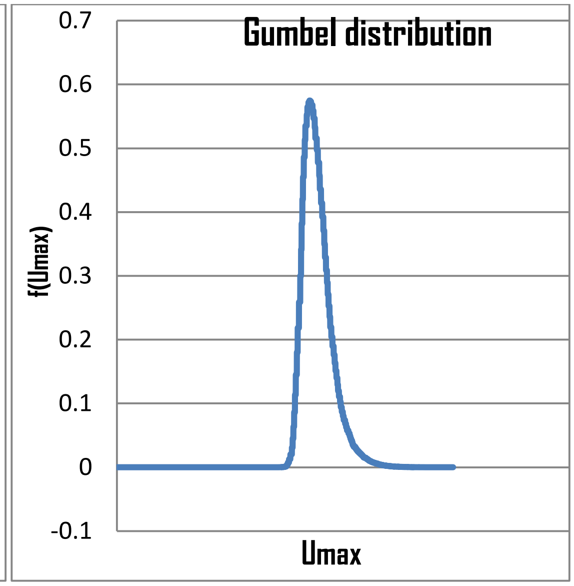
In figure (4-2-3)a which represent the results for December 2002, the values of added turbulence intensity ranged between 0.0044 at wind speed 4 m/s and 0.00167 at 23 m/s, which for March 2003 [figure (4-2-3)b] the values of added turbulence intensity varied between 0.0044 at 4 m/s and 0.00163 at 24 m/s, and for September 2003 [figure (4-2-3)d] the values varied between 0.0044 at wind speed 4 m/s and 0.0023 at 20 m/s.

In figure (4-2-3)c which represent the results for July 2003, the values of the added turbulence intensity ranged between 0.0044 at 4 m/s and 0.0028 at 16.23 m/s.

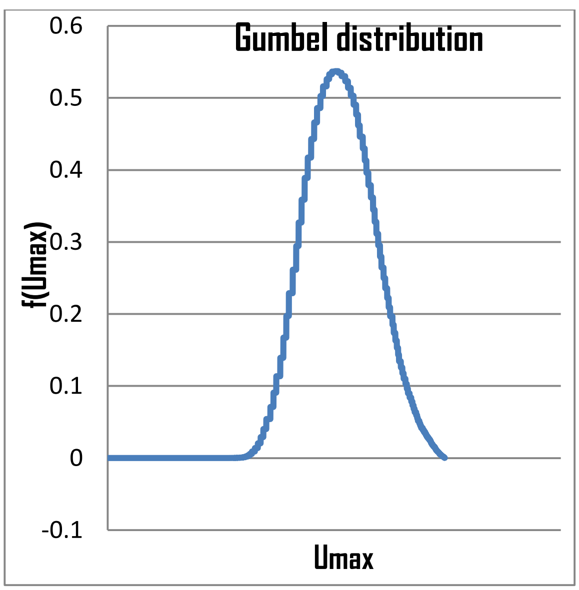
4.3 Estimation of gust extreme wind speed by (Gumbel distribution):



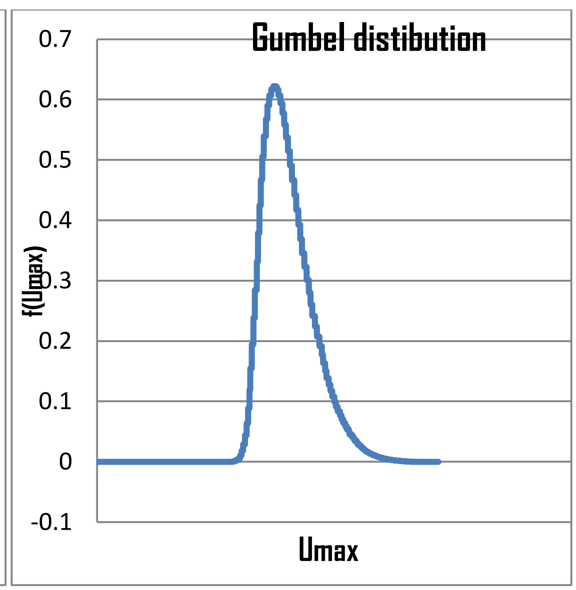
a) Gumbel distribution in December 2002.



b) Gumbel distribution in March 2003.



c) Gumbel distribution in July/2003.



d) Gumbel distribution in September /2003.

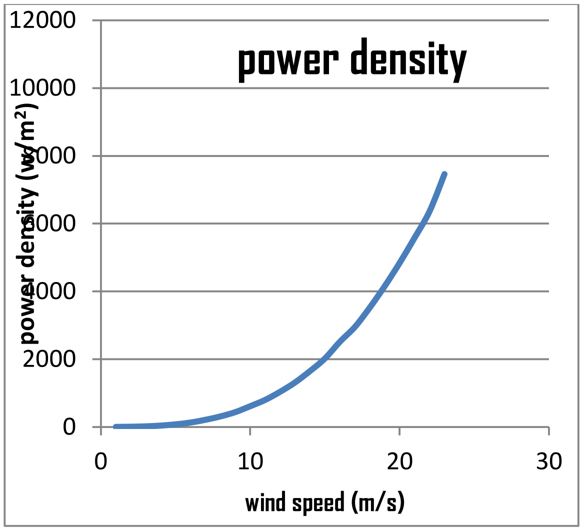
Figure (4-3) shows results of Gumbel distribution according equation (3-23) with standard deviation and maximum wind speed at hub height of 67m.

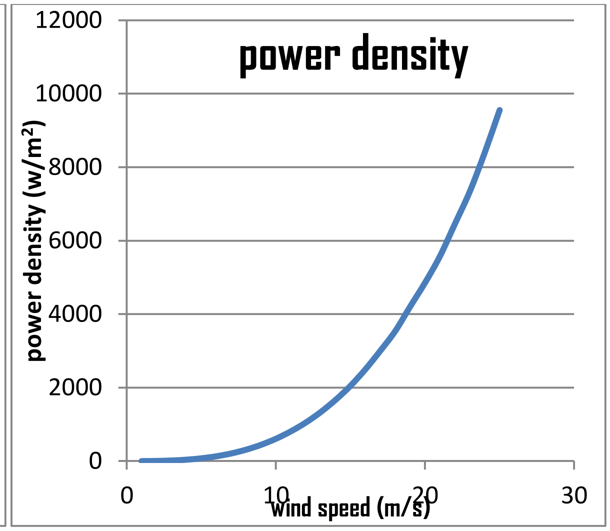
From figure (4-3) we note that high values of Gumbel distribution ranging from 53.71m/s in figure (4-3)c ” With location parameter 12.4356, scale parameter 0.6848 and maximum value at wind speed 11.39m/s” To 71m/s in figure (4-3)a ” With location parameter 10.6935, scale parameter 0.516556 and maximum value at wind speed 9.36m/s “.

While high value in figure (4-3)b is 57.3m/s with location parameter 11.245 , scale parameter 0.638 and maximum value at wind speed 11.4m/s, while high value in figure (4-3)d is 62.19m/s with location parameter 10.2136, scale parameter 0.5911 and maximum value at wind speed 9.2m/s, however, here we must based high value.

4.4 Power density:

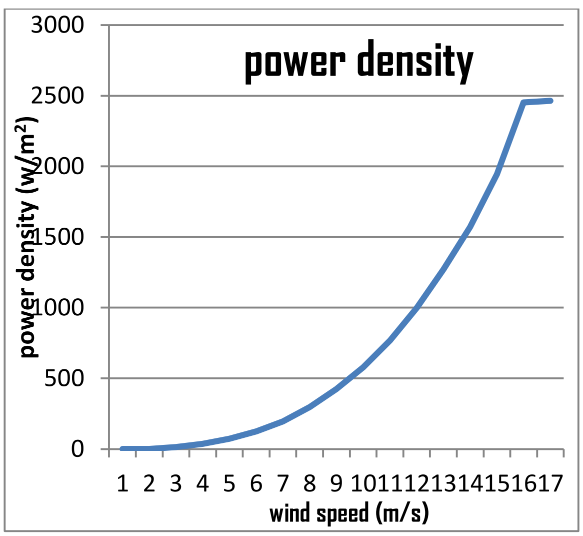
Different values maximum power density depending on the air density and averages wind speed (over 10min). Where the air density directly proportional to power density, while wind speed is the more important variable, that because the power density is directly proportional to the cubic wind speed.

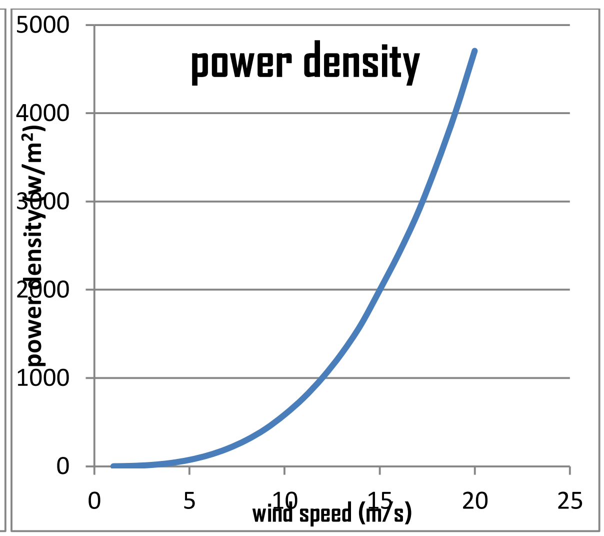




a) Power density in December/2002

b) Power density in March/2003





c) Power density in July/2003

d) Power density in September /2003

Fig (4-4) shows power density for four months according equation (3-15) with temperature and pressure wind speed at ground level.

In figures (4-4)b and (4-4)c, we note that the variation of maximum power density between 2.46Kw/m^2 with air density 1.15 Kg/m^3 in July 2003 to about 9.55Kw/m^2 with air density 1.21 Kg/m^3 in March 2003.

while in figures (4-4)b and (4-4)c the maximum values of power density reaches to 7.39Kw/m^2 with air density 1.21Kg/m^3 in December 2002 and 4.71Kw/m^2 with air density 1.16 Kg/m^3 September 2003 respectively.

Chapter V:
Conclusion &recommendations

5-1 Conclusion :

In this study classified Dernah-Libya Site by using measured data, where was the average wind speed at hub height (8.21 m/s), while the estimated turbulence intensity at 15 m/s in three cases:
at the distance between the turbines according recommendations IEC standard and roughness length =0.001, the distance between the turbines less than recommendations IEC standard and roughness length =0.001and the distance between the turbines according recommendations IEC standard and roughness length =0.003 where were (0.107821, 0.1078, 0.12228) respectively
from this results the wind farm classified in first and second cases in class CIII, while in the third case was in class BIII. and the highest estimated wind speed possible occurrence in Site is 71 m/s.

5-2 Recommendation:

1. study of effect the distance between turbines on classification and site assessment wind farm

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Appendixes

Appendix (1):

1. Power & CT curves of wind turbine.

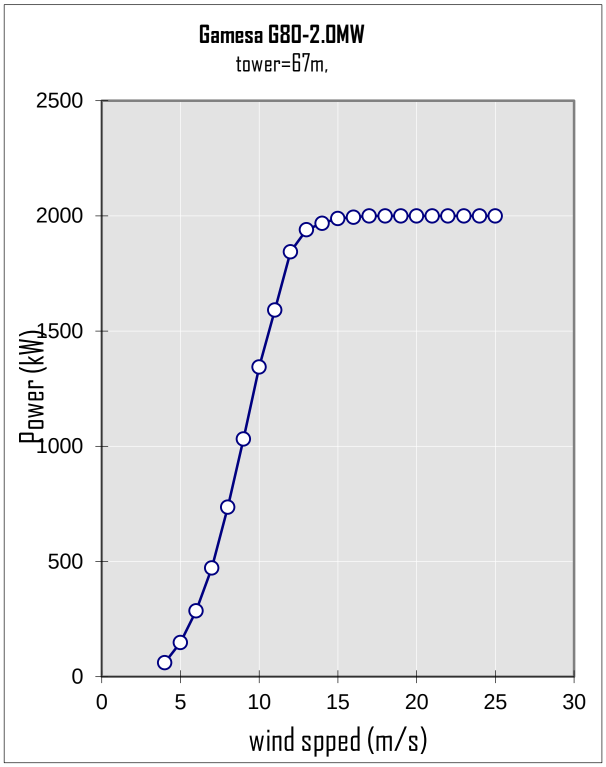


figure (A-1) power curve of Gamesa G80-2.0MW with hub height 67m.

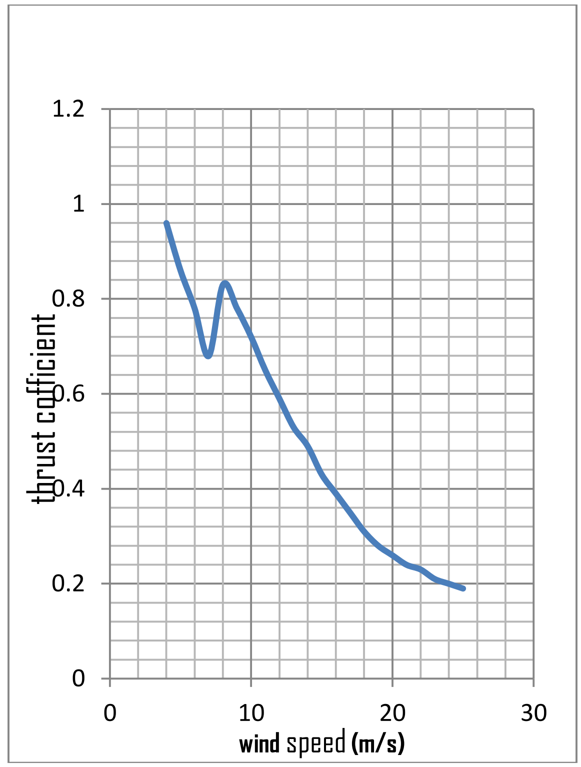
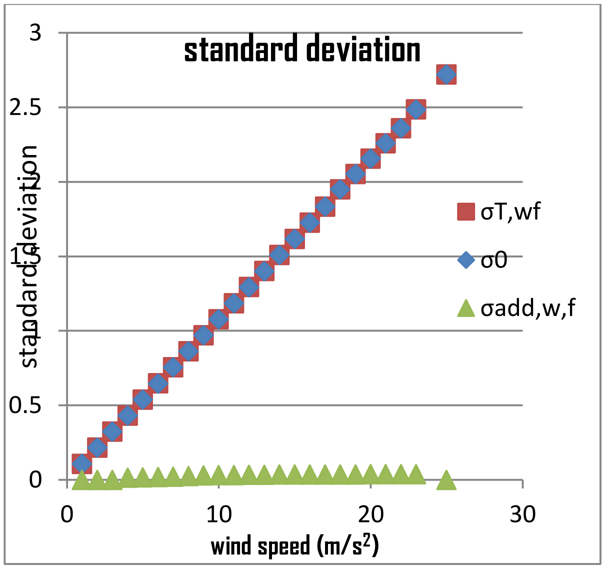


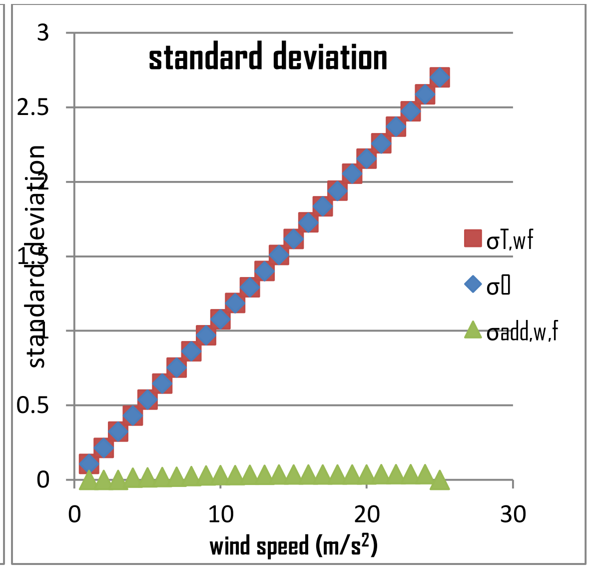
figure (A-2) thrust cofficient of Gamesa G80-2.0MW.

Appendix (2):

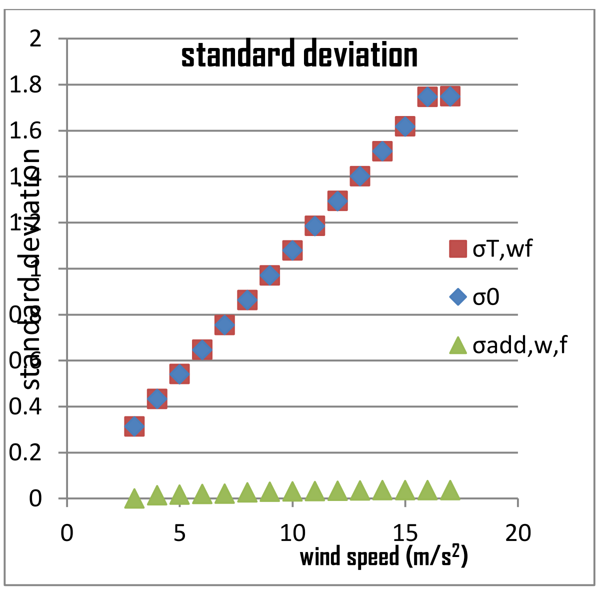
Standard deviation of Dernah site



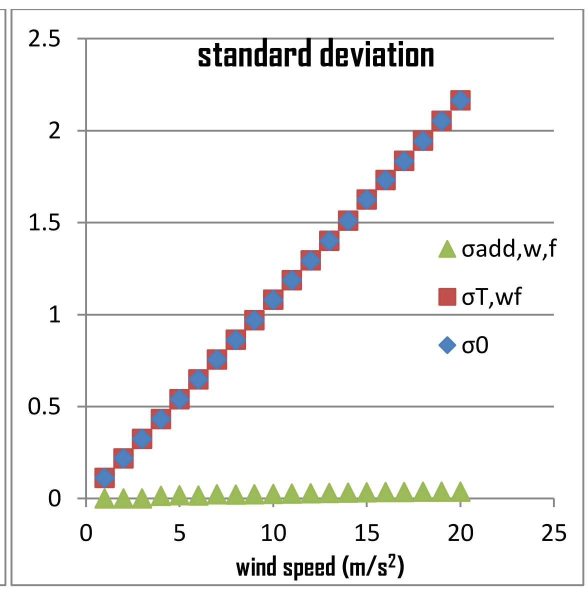
a) Standard deviation in December /2002.



b) Standard deviation in March/2003.



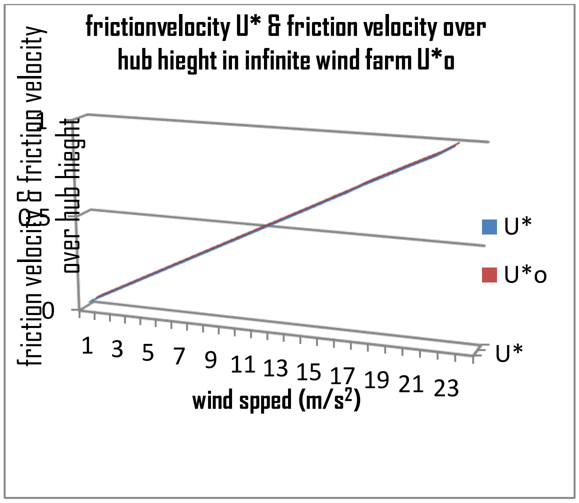
c) Standard deviation in July/2003



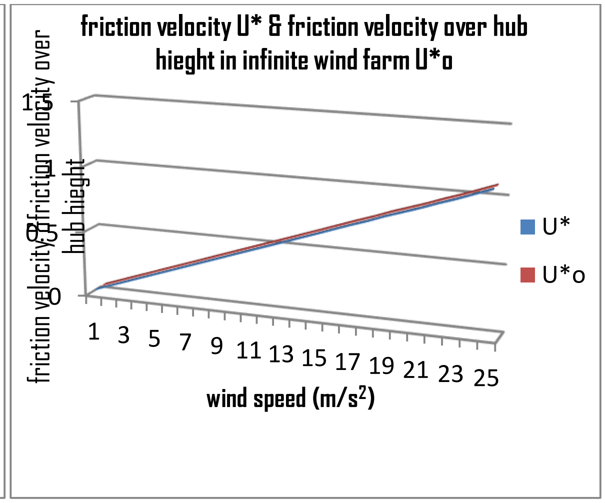
d) Standard deviation in September/2003

figure (A-3) standard deviation for four months at hub height 67m.

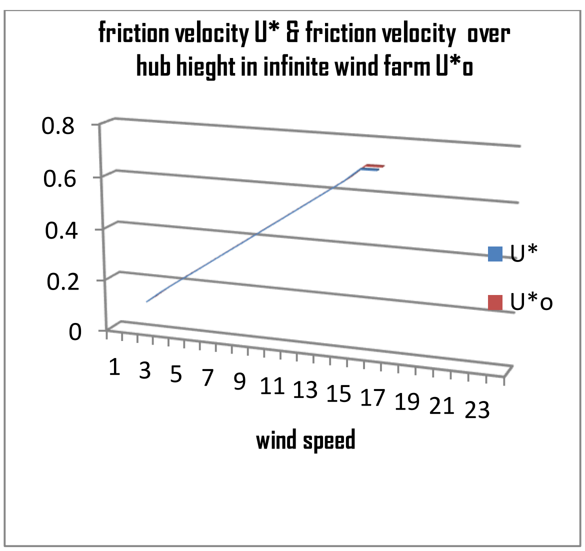
Appendix 3: friction velocity and friction velocity over hub height.



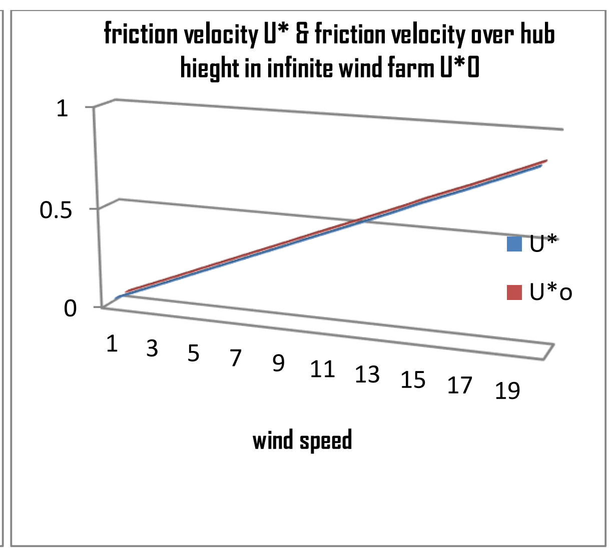
a) friction velocity and friction velocity over hub height in December /2002



b) friction velocity and friction velocity over hub height March/2003



c) friction velocity and friction velocity over hub height July/2003



d) friction velocity and friction velocity over hub height September /2003

figure (A-4) friction velocity and friction velocity over hub height at height 67m.

Appendix 4: comparison between our project and Mtorres

	Our project	**Mtorres**
Type of turbine	Gamesa G80	Mtorres
The average wind speed	8.21m/s	8.45 m/s
Hub height	67m	71m
Wind shear	0.15	0.1056
Air density	1.18	1.178
U_{ref}	36.27	36.1
ruggedness length	0.01	0.03
Turbulence intensity	0.11	0.1256
Wind farm class	IIIC	IIIB