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

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ABSTRACT

The certification and testing of wind turbines is very important to provide assurance to all entities involve, 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 standar. For wind farm classification according to IEC most estimate three factors (the average wind speed at hub height, turbulence intensity and maximum gust wind speed possible occurrence), while the data used were recorded at (10 m) above the ground on a time scale of (10 min) at the Dernah site and selected type of turbine to be as example for this methodology, it's Gamessa 80 – 2MW.

Here we can estimate the wind speed at turbine hub height measured wind speeds at different altitudes, while the turbulence intensity was estimated in three cases; when the roughness length is (0.001, 0.01 and 0.03m) 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. 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.

Key words: wind farm, wind speed, turbulence intensity, roughness length.

الملخص

يعد اعتماد واختبار توربينات الرياح أمرًا مهمًا للغاية لتوفير الضمان لجميع الكيانات المشاركة في مشاريع طاقة الرياح حيث توجد معايير وطنية في الدنمارك وألمانيا وهولندا. نشرت اللجنة الكهروتقنية الدولية (IEC) سلسلة من المعايير الدولية. معايير IEC، التي تحمل الرقم المرجعي 1- 61400 وتحمل عنوان أنظمة مولدات توربينات الرياح، تم اعتمادها بالفعل من قبل العديد من البلدان حول العالم أو يتم استخدامها كأساس لتطوير المعايير الوطنية.

بالنسبة لتصنيف مزرعة الرياح حسب IEC تقدر معظم العوامل الثلاثة (متوسط سرعة الرياح عند ارتفاع المحور، وشدة الاضطراب، والحد الأقصى لسرعة الرياح المحتملة الحدوث)، في حين تم تسجيل البيانات المستخدمة على ارتفاع (10 أمتار) فوق سطح الأرض على مقياس زمني قدره (10 دقائق) في موقع (الفتائح - درنة)، وتم اختيار نوع من التوربينات لتكون مثالاً لهذه المنهجية، وهي Gamessa 80 – 2MW.

هنا يمكننا تقدير سرعة الرياح عند ارتفاع محور التوربينة وقياس سرعات الرياح على ارتفاعات مختلفة، في حين تم تقدير شدة الاضطراب في ثلاث حالات؛ عندما تكون الخشونة سطح الارض (0.001، 0.01، 0.03 م) وتكون المسافة بين التوربينات حسب توصيات اللجنة الكهرتقنية الدولية (IEC)ت؛ أي أن تكون المسافة بين التوربينات ثلاثة أضعاف قطر توربينات الرياح. حيث تم التصنيف في الحالتين الأولى والثانية في الصنف CIII، بينما الحالة الثالثة كانت في الصف BIII. وأقصى سرعة رياح مقدرة في الموقع كانت 71 م/ث.

Introduction

Turbulence intensity is crucial for wind turbine design and power estimation. It exposes turbines to complex meteorological conditions, causing fatigue and static loads on blades. Wind fluctuation models are essential for understanding turbulent systems. The IEC 61400 standard provides a normal turbulence model (NTM) for calculating induced loads on turbines, which are then used in wind tunnels to test blade resistance before use (8).

Certification and testing of wind turbines ensures assurance for all parties involved in wind energy projects, including wind farm operators, banks, and governments. Independent institutions or individuals conduct the certification task, confirming conformance with normative documents.

The wind turbine type certification involves a two-part design assessment, including operation and security testing, load calculations, which are then compared with relevant standards and recommendations.

The type characteristics of a wind turbine are determined through characteristic measurements, which include power performance and power quality tests (4).

To develop a wind farm, identify land with enough wind for a commercial project through wind-study assessments using historical wind data and weather archives. Evaluate environmental conditions like wind speed, standard deviation, pressure, and temperature, using long-term records from nearby meteorological stations. Classify and assess the site based on wind flow analysis, considering topography and land roughness. Estimate wind speed at different heights using the 1/7th wind power law, and calculate the wind shear coefficient using measured values. This method is cost-effective and reliable for estimating wind speed at hub height (10).

1. Materials and Methods

1.1. 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 factor: The size, availability, reliability, warranty, proximity of operation and maintenance teams and roads.

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

Figure 1: Dernah site in Libya map.

2. Theory and Calculation

2.1. Wind speed variation with height:

A conventional approach for describing the increase in wind speed with height is the logarithmic equation (2):

$$\boldsymbol{U_H = U_{ref}\left(\frac{ln\left({}^{H}/_{Z_0}\right)}{ln\left({}^{Href}/_{Z_0}\right)}\right)} \qquad (1)$$

2.2. Turbulence intensity of wind speed: the turbulence intensity is the most basic measure of turbulence. It is the ratio of the wind standard deviation to the mean horizontal wind spee and it is frequently in the range of 0.1 to 0.4.(4), (5).

$$\boldsymbol{I = \frac{\sigma}{U}} \qquad (2)$$

Turbulence analysis determines the type of turbine suitable for a wind energy project. Because wind turbines must withstand a variety of wind conditions, the (IEC) sets design standards. IEC 61400-1:2019 has two components, one for wind speed and another for turbulence, as shown in Table (1)(5).

Table 1: *Wind Turbine Classes according to IEC 61400-1 (4rd)*

Wind turbine class		I	II	III	S
$\boldsymbol{U_{ave}}$	**(m/s)**	10	8.5	7.5	Values specified by the designer
$\boldsymbol{U_{ref}}$	**(m/s)**	50	42.5	37.5	
	Tropical $\boldsymbol{U_{refT}}$	57	57	57	
A+	$\boldsymbol{I_{ref}}$ (-)	0.18			
A	$\boldsymbol{I_{ref}}$ (-)	0.16			
B	$\boldsymbol{I_{ref}}$ (-)	0.14			
C	$\boldsymbol{I_{ref}}$ (-)	0.12			

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

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

A+: designates the category for very higher turbulence characteristics,

$\boldsymbol{A}$: designates the category for higher turbulence characteristics,

$\boldsymbol{B}$: designates the category for meduem turbulence characteristics,

$\boldsymbol{C}$: designates the category for lower turbulence characteristics and

$\boldsymbol{I}_{\boldsymbol{ref}}$:is the expected value of the turbulence intensity at 15 m/s.(5)

2.3. Vertical shear and its relation to turbulence: the turbulence scale is proportional to height and the shear stress is independent of height. It is discovered that a logarithmic model works well for the vertical wind speed profile (1).

$$\frac{U}{U_*} = \frac{1}{\kappa} \, LN \, \left(\frac{Z}{Z_0}\right) \qquad (3)$$

2.4Ambient Turbulence within the Wind Farm: A model for the effect of a large wind farm on the planetary boundary layer is shown in the figure (3-1) (7).

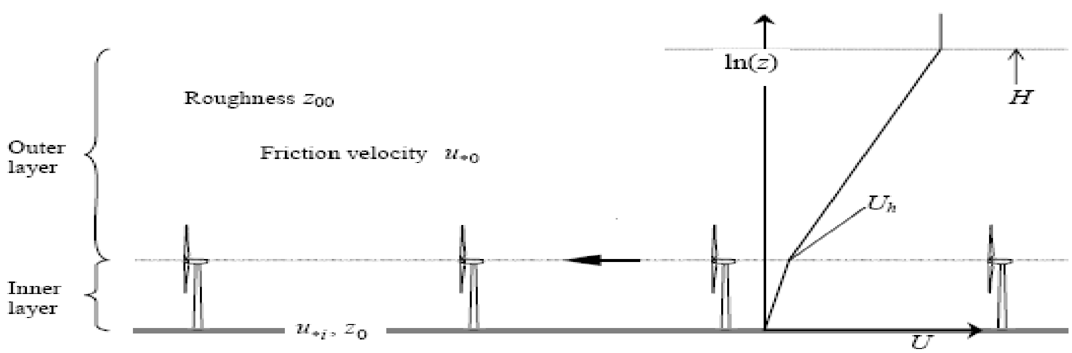


Figure 2. In order to estimate the general decrease in mean wind speed and increase in turbulence intensity, an infinitely large wind farm is considered (7).

$$\frac{U}{U_{*0}} = \frac{1}{\kappa} \, ln \, \left(\frac{Z}{Z_{00}}\right) \qquad (4)$$

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

$$\boldsymbol{Z_{00} = h_H \,.\, EXP\left(-\kappa \Big/ \sqrt{c_t + \left(K \Big/ LN\left(\frac{h_H}{Z_0}\right)\right)^2}\right)} \quad (5)$$

And

$$\boldsymbol{c_t} = \frac{\pi\, c_T}{8\, s_r\, s_f} \quad (6)$$

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

$$\sigma_0 \approx \frac{U_0}{LN(^{h_H}/_{Z_0})} = \frac{U_*}{\kappa} \quad (7)$$

$$I_0 = \frac{\sigma_0}{U_0} \quad (8)$$

We can be estimated the turbulence over the wind farm

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:

$$\sigma_{T,wf} = \frac{U_{*0}}{\kappa} \quad (9)$$

the turbulence intensity in the wind farm is defined referring to free flow wind turbine hub height wind speed as (4):

$$I_{T,wf} = \frac{\sigma_{T,wf}}{U_0} \quad (10)$$

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 (6):

$$\sigma^2{}_{T,wf} = \sigma^2{}_0 + \sigma^2{}_{add,wf} \quad (11)$$

$$I^2{}_{T,wf} = I^2{}_0 + I^2{}_{add,wf} \quad (12)$$

From this equation we can find added wind farm "ambient" turbulence as (9):

$$I_{add,wf} = \sqrt{{I_{T,wf}}^2 - {I_0}^2} \quad (13)$$

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

$$\Sigma'_{T,wf} = \frac{1}{2}\left(\sqrt{\sigma'_{add,wf} + \sigma_0{}^2} + \sigma_0\right) \tag{14}$$

Where: $$\sigma'_{add,wf} = \frac{0.36\,U_h}{1+0.2\sqrt{{d_r\,d_f}/{C_T}}} \tag{15}$$

3. Results and Discussion

The calculation is based on specification of wind turbine known as Gamessa G80-2.0MW which has a power. And Utilizing wind data of derrnah site, which was taken from REAOL.

3.1. turbulence intensity the surface roughness length = 0.001.

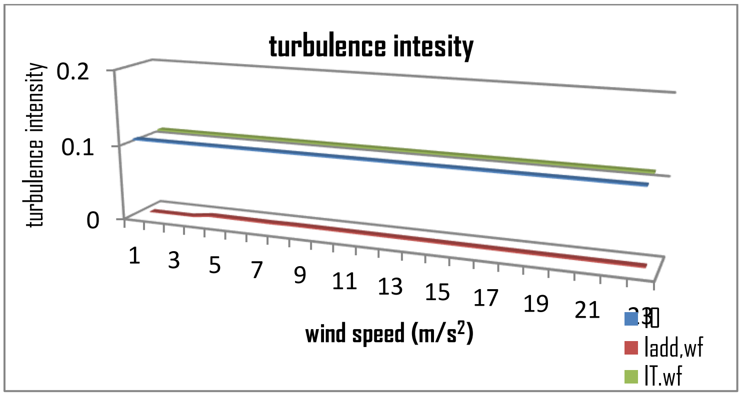
when wind speed is low, we note that the value of wind farm turbulence intensity is height, that because the turbulence intensity inversely proportional with wind speed and the added turbulence intensity has height value and equal in all figures, where it has a value about 0.107843, while decreases at 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 (3-1) a to (3-1) d.

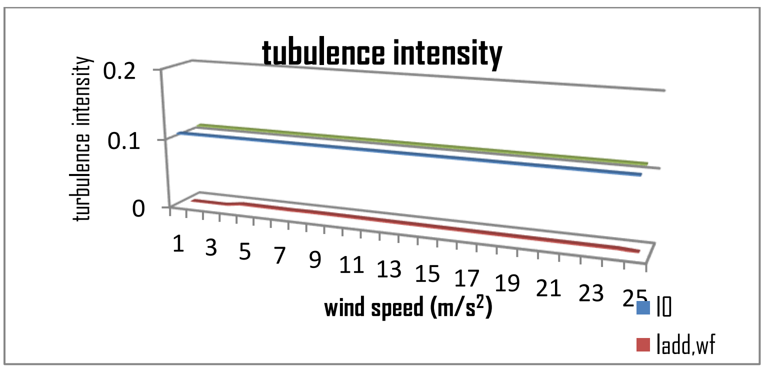
From these figures it was found that the added "ambient" wind farm turbulence was small. Therefore, the wind farm turbulence intensity was close to the ambient turbulence intensity. Generally, turbulence intensity at 15 m/s was determined as 0.1078.

In figure (3-1) 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 (3-1) b] the values of added turbulence intensity varied between 0.0036 at 4 m/s and 0.001645 at 24 m/s.

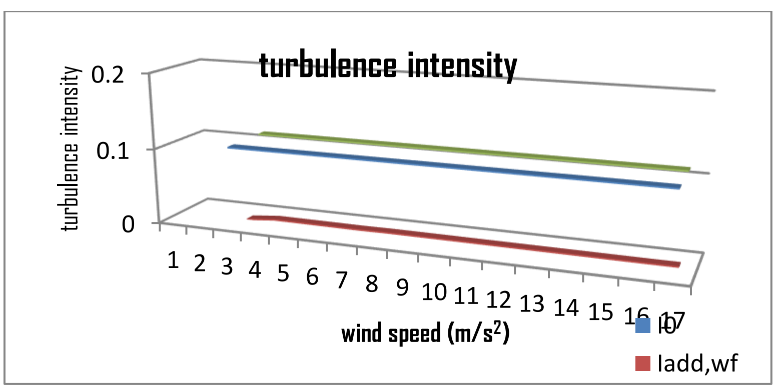
In figure (3-1) c which represent the results for July 2003, the values of the added turbulence intensity ranged between 0.0036 at 4 m/s and 0.0023 at 16.23 m/s which for September 2003 in figure (3-1) d the values varied between 0.0036 at wind speed 4 m/s and 0.0019 at 20 m/s.



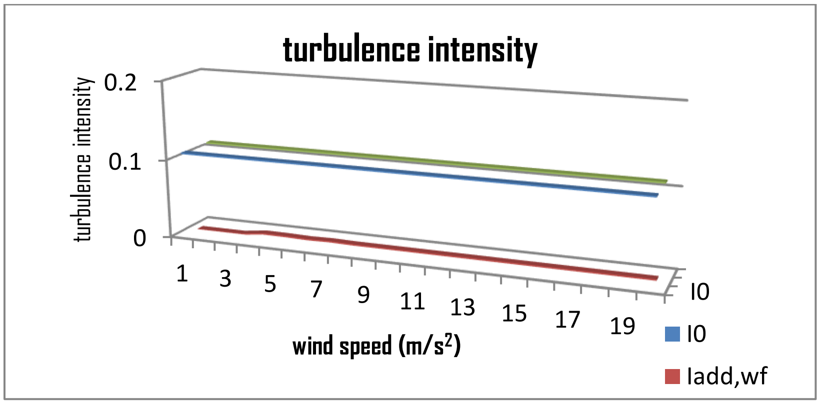
a) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in December / 2002



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 (3-1) turbulence intensity, ambient wind farm turbulence and wind farm turbulence intensity

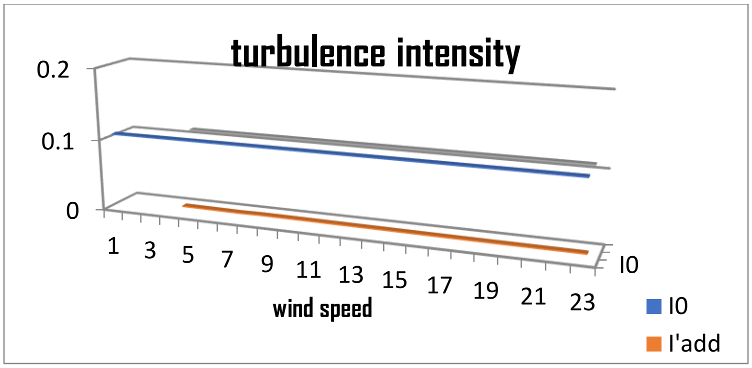
for four months with s_f =480, s_r = 320m and z_0=0.001.

3.2. turbulence intensity when the surface roughness length =0.01.

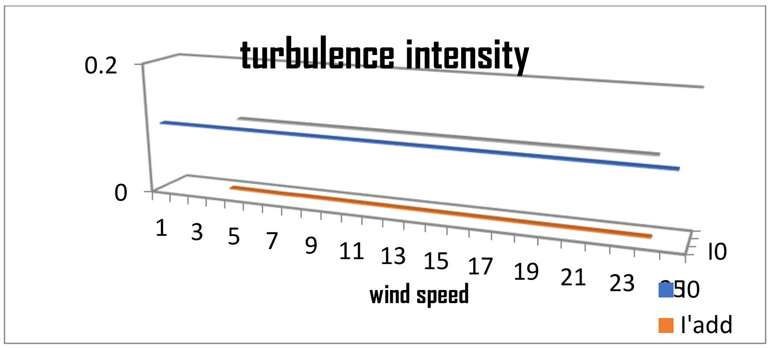
In this case the added turbulence intensity has value 0.00444 at 4 m/s, while decreases at increases the wind speed, until its value reaches of 0.00209 in winter and 0.00281 In summer, while its value reaches 0.00203and 0.00232 in spring and autumn, Generally, the turbulence intensity at 15 m/s was 0.1078.

In figure (3-2) 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 (3-2) b] the values of added turbulence intensity varied between 0.0044 at 4 m/s and 0.00204 at 24 m/s.

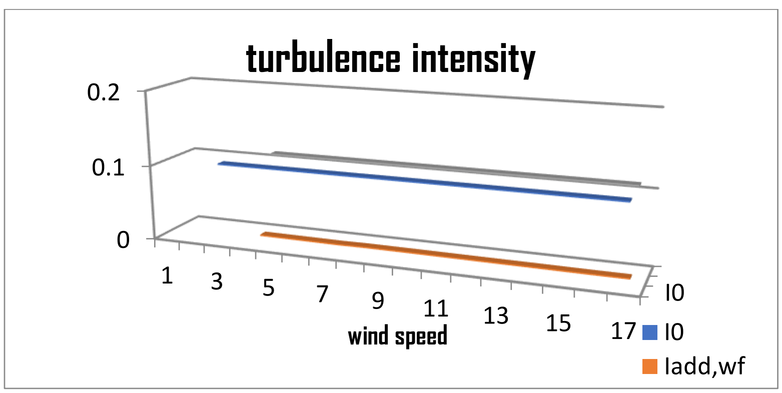
In figure (3-2) c which represent the results for July 2003, the values of the added turbulence intensity ranged between 0.0044 at 4 m/s and 0.0028 at 16.23 m/s which for September 2003 in figure (3-2) d the values varied between 0.0044 at wind speed 4 m/s and 0.0023 at 20 m/s.



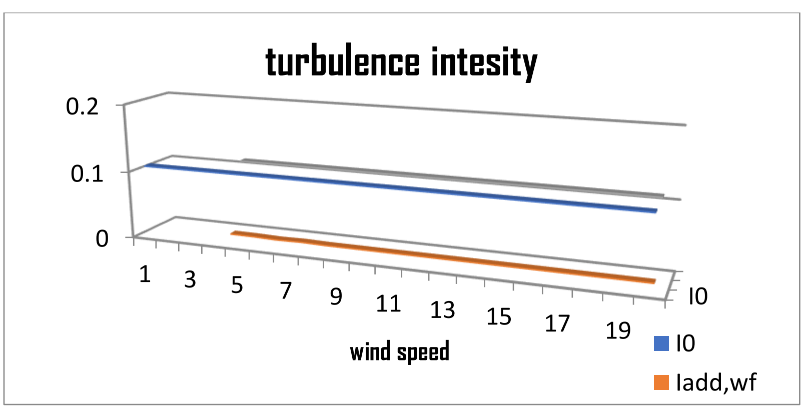
a) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in December / 2002



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



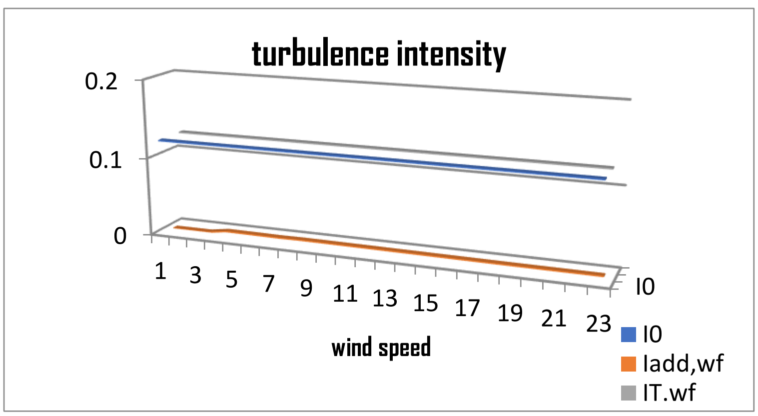
c) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in July / 2003



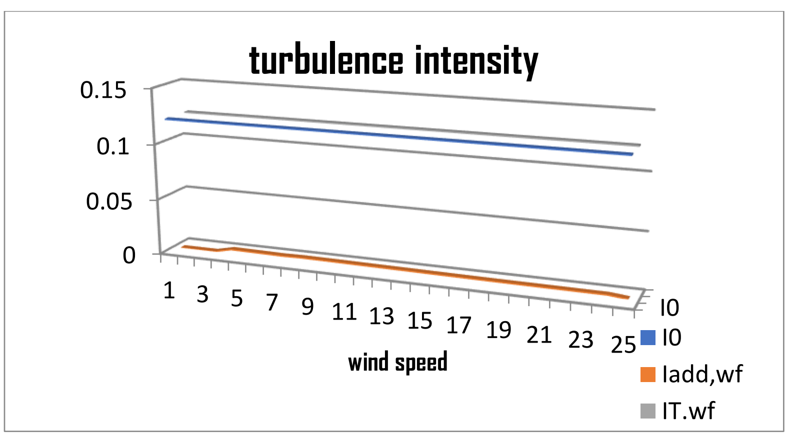
d) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in September /200 figure (3-2) turbulence intensity, ambient wind farm turbulence and wind farm turbulence intensity for four months with s_f =480, s_r = 320m and z_0=0.01.

3. 3. turbulence intensity when the surface roughness length =0.03.

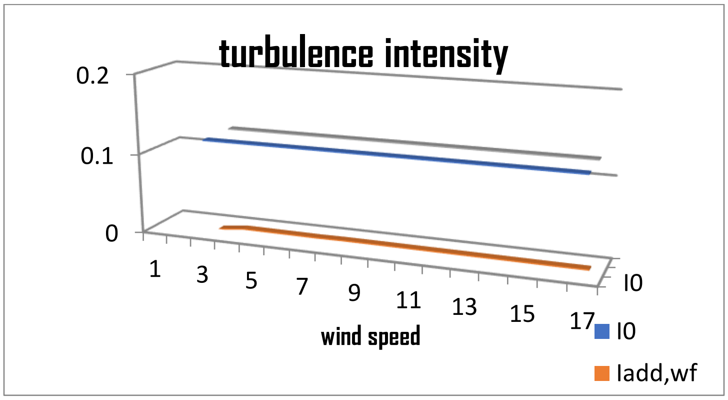
Here the surface roughness length is changed, the ambient turbulence intensity has value (0.12226), while the added turbulence intensity has value 0.00358 at 4 m/s, while decreases at increases the wind speed, until its value reaches of (0.00167), (0.00163), (0.00186) in winter, spring and autumn respectively,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



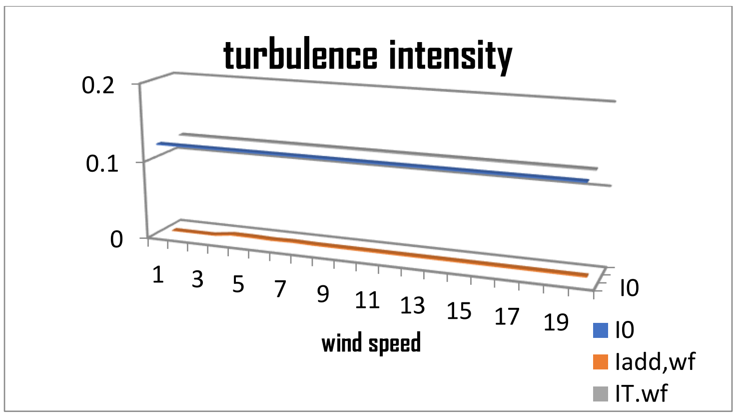
a) Added turbulence intensity, ambient turbulent intensity and wind farm turbulence intensity in December / 2002



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 (3-3) 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 (3-3) 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 (3-3) 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 (3-3) d] the values varied between 0.0044 at wind speed 4 m/s and 0.0023 at 20 m/s.

In figure (3-3) 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. Conclusions

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 these 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.

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