Ambient Turbulence Intensity Calculation for Al-Nasiriyah Province in Iraq

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Abstract

Before setting a turbine in a wind farms allocated for power generation, it must be know the appropriate turbine class for that site depending on the turbulence intensity of the winds in the studied area and the IEC-61400 standard. The importance of identifying a class of wind turbine is due to the complex environmental conditions that produce turbulent air which, in turn, may cause damage to the turbine blades and weakness in the performance. Therefore, the ambient turbulence intensity is a very important factor in determining the performance and productivity of the wind turbines.

In this research we calculate Turbulence Intensity "TI" in the province of Nasiriyah, south of Iraq (Lat. 31.052049 , Lon. 46.261021) for the years 2008, 2009, and 2010, in addition to determine the wind turbine class that appropriate for the site after comparison with the Normal Turbulence Model "NTM" belongs to IEC 61400-1, edition2 and IEC 61400-1, edition3.

Keywords: wind energy, IEC 61400-1, turbulence intensity, normal turbulence model.

حساب شدة اضطراب الرياح لمحافظة الناصرية في العراق

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الخلاصة

أن معرفة صنف توربين الرياح الملائم لموقع معين قبل نصبه في مزارع توليد الطاقة الكهرابائية يعتمد بالاساس على شدة اضطراب الرياح هناك وعلى المعيار IEC-61400. والسبب في حتمية تحديد صنف التوربين يعود الى تعرضه بعد النصب الى ظروف بيئية معقدة تسبب اضطراب شديد في الرياح مما يؤدي الى تلف عنقات التوربينات وضعف في الأداء ، لذا فان الاضطراب هو عامل مهم جدا في تحديد أداء توربينات الرياح وأنتاجيتها.

في هذه البحث تم حساب شدة اضطراب الرياح في محافظة الناصرية (Nasiriyah) الواقعة جنوب العراق (بخط عرض 31.052049 وطول 46.261021) وللسنوات 2008 و 2009 و 2010، اضافة الى تحديد صنف توربين الرياح الملائم للنصب في ذلك الموقع بعد المقارنه مع نموذج الاضطراب الطبيعي القياسي (NTM) الذي يقع ضمن كلا من IEC 61400-1,edition2 و IEC 61400-1,edition3.

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1- Introduction

Turbulence intensity is the standard deviation of the wind speed within a time step divided by the mean wind speed over the same time step. TI 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 winds speeds is of greater interest and concern to wind turbine manufacturers [1].

Turbulence analysis determines the suitable types of turbine designs for a wind energy project. Because a large amount of turbulence will generate a large amount of fatigue loadings on the construction, which increasing the risk of system breakdown, Therefore it is a major concern to perform more measurements and further investigate the turbulence characteristics in complex environments and the effect that will affect on wind turbine construction. Design standards have been developed by the International Electrotechnical Commission (IEC) 61400-3:2005 [2].

2- TI Measurement

In wind resource analysis, turbulence is measured by turbulence TI, which is a dimensionless quantity. Turbulence intensity is the ratio of wind speed standard deviation to the mean of wind speed, measured from the same set of data samples [3].

If u is the wind speed variable, u_m is the mean of wind speed, and σ is the standard deviation of longitudinal wind speed of measured data, then the measured 10 minute turbulence intensity, TIu, is shown by the following equation [3]:

$$TI_u = {}^{\sigma_u}/_{u_m} \qquad (1)$$

Due to this definition TI_u can become infinitely large when the wind speed reaches zero.

3- Percentile values from a normal distribution

The 50th and 90th percentiles in standard Normal Turbulence Model "NTM" can be understood from Figure 1. The figure illustrates a bell-shaped normal distribution. The mean value is represented by the 0-line. Each division on the x-axis of the distribution is the size of the standard deviation, σ. The cumulative percentage together with percentile values of each section is shown underneath the distribution curve. 50% of observation is represented by the middle line, while the 90% of observation is represented by the red line, and thereby the 50th percentile is determined by the mean value as $\overline{TI_u}$, while 90th percentile is determined by the mean value plus $1.28 \times \sigma$ as $\overline{TI_u} + 1.28\sigma_{TI}$ [2].

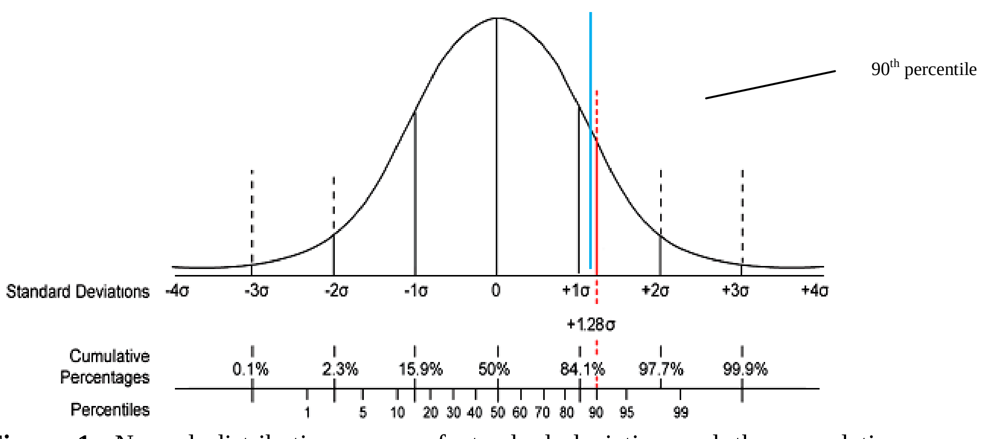

Figure 1- Normal distribution curve of standard deviation and the cumulative percentage together with percentiles. The red line represents the 90th percentile; middle line represents the 50th percentile [2].

In IEC 61400-1 model, the TI in the 2nd edition is described in a different way from that in the 3rd edition. The former called "characteristic TI" and the latter "representative TI" [3].

IEC61400-1, second edition, defines the ‘characteristic TI’ which is determined from the mean plus standard deviation (84th percentile) of random ten-minute measurements. Load cases are defined by the characteristic TI at 15m/s, called I_{15}.

IEC61400-1, third edition, defines the 'representative TI' which is calculated from the mean +1.28 times standard deviation (90th percentile) of random ten-minute measurements. Load cases are defined by the reference TI I_{ref}, which is equal to the mean turbulence intensity [5].

According to IEC61400-1 edition 2, NTM for small wind turbine states that the expected standard deviation of longitudinal wind σ1, should be given by [5]:

$$\sigma_1 = \frac{I_{15}(15\, m/s + aV_{hub})}{a+1} + \Delta\sigma_1 \qquad (2)$$

Where, I_{15} is the assumed TI at a mean wind speed of 15*m/s* and *a* is a slope parameter. as seen in table 1, these parameters have a constant value of I_{15} =18% and 16% for class A and B respectively, where *a* = 2 for class A, *a*=3 for class B (see Table1). The term $\Delta\sigma_1$ in eq.2 is a modification which let the model correspond to different percentile values.

$$\Delta\sigma_1 = 2(p-1)\, I_{15} \qquad (3)$$

Where,

σ_1 = is the hub-height longitudinal wind velocity standard deviation

a = is the slope parameter for turbulence standard deviation model

I_{15} = is the characteristic value of hub-height TI at a 10 min average wind speed of 15 m/s and a function of turbine class (see Table 1).

V_{hub} = is the wind speed at hub height averaged over 10min, see Table 1 [5].

p = is determined from the normal probability distribution function which corresponds to *p* = 0 for the 50th percentile, and *p* = 1.28 for the 90th percentile, and *p* =1 for the 84th percentile which defines the characteristic TI.

Table 1- IEC 61400-1: 1999 Edition 2 **[5]**

WTG Class		**I**	**II**	**III**	**IV**	**S**
V_{ave} (m/s)		10	8.5	7.5	6.0	manufacturer
V_{ref} (m/s)		50	42.5	37.5	30.0	
A	I_{15}	0.18	0.18	0.18	0.18	
	a	2	2	2	2	
B	I_{15}	0.16	0.16	0.16	0.16	
	a	3	3	3	3	

The expected 10 minutes mean TI, is given by normalizing σ_1 with mean wind speed at hub height [3] i.e.:

$$TI = \frac{\sigma_1}{V_{hub}} \qquad (4)$$

According to IEC61400-1 edition 3, NTM for *large wind turbine* states the expected standard deviation σ_1 is described based on an approximation of the 90th percentile of the standard deviation of the longitudinal wind speed V_{hub} by [5]:

$$\sigma_1(90^{th}) = I_{ref}\left(0.75V_{hub} + 5.6\frac{m}{s}\right) \qquad (5)$$

While the distribution value of the 50th percentile standard deviation of the large wind turbine (mean), is given as guidance by the following expression [6].

$$\sigma_1(50^{th}) = I_{ref}\left(0.75V_{hub} + 3.75\frac{m}{s}\right) \qquad (6)$$

Where, I_{ref} = is the representative value of hub-height TI at a 10 min average wind speed of 15 m/s and a function of turbine class (see Table 2).

Table 2- IEC 61400-1: 2005 Edition 3 **[5]**

WTG Class	**I**	**II**	**III**	**S**
V_{ave} (m/s)	10	8.5	7.5	manufacturer
V_{ref} (m/s)	50	42.5	37.5	
A I_{ref}	0.16			
B I_{ref}	0.14			
C I_{ref}	0.12			

Turbulence intensity *I* in NTM for both large and small wind turbine, is given by normalizing σ_{90} and σ_{50} with mean wind speed, as follows [6]:

$$I_{90} = \frac{\sigma_{90}}{V_{hub}} \quad (7)$$

$$I_{50} = \frac{\sigma_{50}}{V_{hub}} \quad (8)$$

Here, σ_{50} is bin-average of measured 10min value; σ_{90} is bin-average of 10min values calculated from σ_{ave} and σ_{σ} by the following equation assuming IEC 61400-1 edition 2 [6]:

$$\sigma_{90} = \sigma_{ave} + \sigma_{\sigma} \quad (9)$$

Here, σ_{σ} is 10min standard deviation bin-average values. In IEC 61400-1 edition 3, Eq.9 represented as [6]:

$$\sigma_{90} = \sigma_{ave} + 1.28 \cdot \sigma_{\sigma} \quad (10)$$

Ambient turbulence intensity in IEC 61400-1 edition 2 given by the representative value for a set of 10-minute time steps, each bin as the averaged value plus standard deviation of turbulence intensity, as follows [5]:

$$TI_{90} = TI_{ave} + \sigma_{TI} \quad (11)$$

Also, the ambient turbulence intensity in IEC 61400-1 edition 3 is the representative TI, for a set of 10-minute time steps, is equal to the 90th percentile of the TI values. Assuming a normal distribution of these values, it represents the mean value plus 1.28 times standard deviations. The mean TI is the mean value of all of the TI data at a particular wind speed **[5]**.

$$TI_{90} = TI_{ave} + 1.28 \cdot \sigma_{TI} \quad (12)$$

4- Wind turbine classes

Turbine wind class is just one of the factors which need to consider during the complex process of planning a wind power plant. Turbine classes are determined by three parameters - the average wind speed, extreme 50-year gust, and turbulence [6].

The three wind classes for wind turbines are defined by an International Electrotechnical Commission standard (IEC), and correspond to high, medium and low wind as follows:

Table 1 and Table 2 show the wind turbine class and subclass according to IEC 61400-1: Edition 2 and Edition 3 respectively.

In general, turbines divided into two types; small wind turbines (SWTs) and large wind turbines (LWTs), and each one of them has its own classes. Tables 1 and 2; define the IEC61400 classification for SWTs and LWTs classes respectively and the relevant characteristics of them are given simply in terms of wind speed and turbulence intensity at sites. Tables 1 and 2; show how turbines are classified from I to S. The S class is for a special design for an environment that is more severe than usual for use. Table 2 shows the classes for large turbines, for which different classes have different turbulence values. For small wind turbine the turbulence value of all wind classes is constant Table 1 [4].

5- Site of investigation

Nasiriyah was selected as an open space site to study turbulence intensity effects on small and large wind turbines. Nasiriyah is the capital of the province of Dhi Qara in Iraqi state on the Euphrates about 225 miles (370 km) southeast of Baghdad. Figure 2 show the position on Iraq map.

data was collected from weather underground site for three years (2008, 2009 and 2010), the results was also compared to the Normal Turbulence Model (NTM), as it is defined for the standard SWT and LWT classes by the IEC (1999) and IEC (2005), respectively.

Figure 2- The site of investigation

6- Results and discussions

The results from this study are presented from the one measuring points (described in 3) in the following years:

a) Jan-Dec 2008. b) Jan-Dec 2009. c) Jan-Dec 2010.

As a consequence of this, the wind material is a bit sparse in a wind energy perspective. Still, these measurements give information about the wind climate of complex sites and they also give a hint of what turbulence characteristics would have been found if also higher wind speeds had been experienced.

i. Standard deviation of wind speed calculations

The standard deviation of wind speed σ is plotted as a function of mean wind speed, u_m, in both Figures 3 and 4. The red dots represent each of calculated σ_u value. A linear regression is calculated, with the use of the least square method, and drawn as a pink color line through all of the σ_u points. The calculated standard deviation are compared to the NTM given by Equation 2, where the orange, black and green lines represents the three turbine classes A, B and C respectively (see Figures 3 and 4), such that the turbine classes in the three left graph represent the 50th percentile, while the turbine classes in the three right graph represent the 90th percentile.

After substitution variables values in eq.2 in case of 90th percentile of the NTM we get $\sigma_u = 0.12\,u_m + 1.00$. This mean that the 90th percentile of the NTM has an initial magnitude of $\sigma_u = 1m/s$ for u_m= 0 m/s which is a physical impossibility and should only be seen as a theoretic value. This model parameter is justified in the application of wind turbines since wind speeds below the cut-in wind speed are irrelevant for the loading calculations.

Figure-3, shows the results for January – December 2008, 2009 and 2010 respectively, drawn under NTM that belong to large wind turbine, while Figure 4 drawn under NTM that belong to small wind turbine. There is a large spreading in the resultant values of σ_u at this height and σ_u take both small and large values. For wind speeds lower than 12 m/s there is a large amount of small scale standard deviations. This indicates that the flow at this height, is characterized with small scale turbulent eddies corresponding to situations with no, or only light, turbulence (TI_u < 13 %).

The majority of the σ_u lie underneath the NTM 90th percentile for both cases large and small wind turbines and each year of the study, as shown in Figures 3 and 4. The most extreme value of σ_u is measured starting from at 5 m/s. A comparison with the NTM thus shows that the standard model correctly describes the observed increase of $\sigma_u$with increasing wind speed at this altitude. The linear regression has a deviates from the NTM which is seen to poorly represent the observed turbulence characteristics at 2008 and 2009, while we see a close approximation between this line and NTM at 2010. Since the wind speeds are low, it is difficult to draw any real conclusion about how the pattern will look like for higher wind speeds in such environment but the overall agreement with Figures 3 and 4 can be said to give a hint of what kind of turbulence characteristics might be found there.

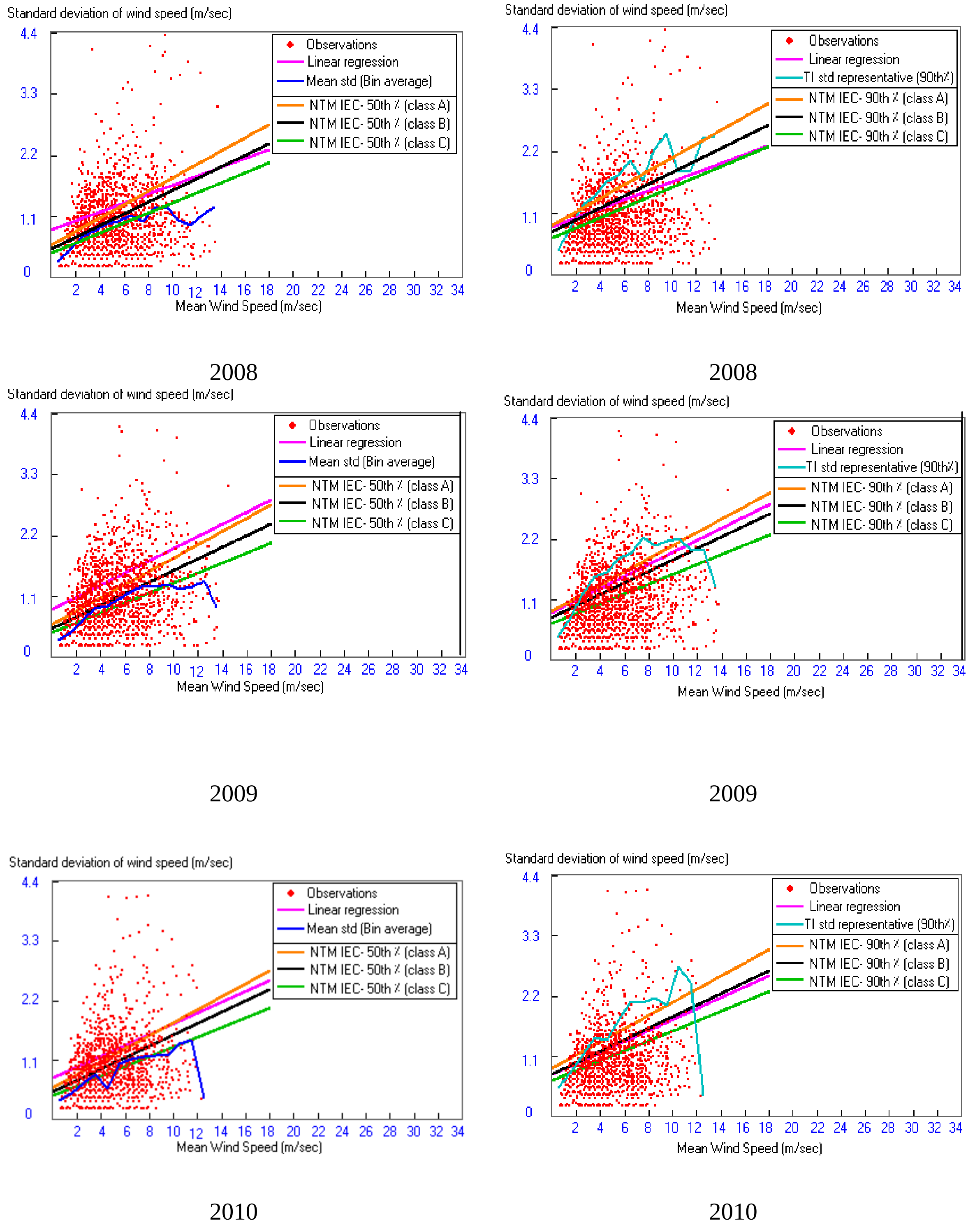

Figure 3- Standard deviation of w. speed as a function of mean w. speed belongs to Nasiriyah site for large wind turbine.

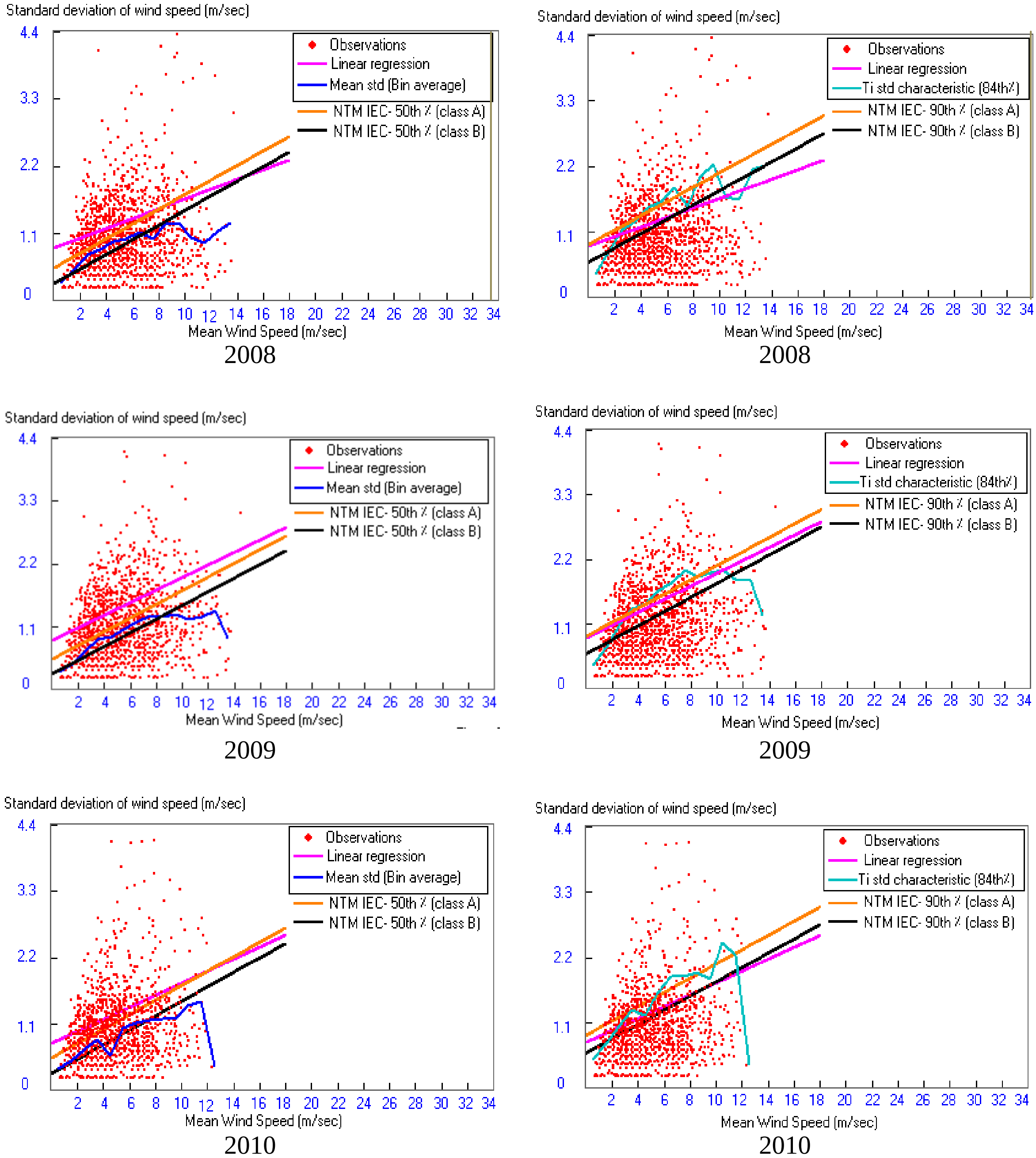

Figure 4- Standard deviation of w. speed as a function of mean w. speed belongs to Nasiriyah site for small wind turbine

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ii. Turbulence intensity calculations

Figures-(5, 6), show the results of turbulence intensity TI_u as given by equation 1, plotted as a function of mean wind speed (red dots). It shows the normal turbulence model values "NTM", given by equation 4, for the 50th the percentile under three classes A, B and C, which are represented by three colors (orange, black and green respectively). In addition, the 90th percentile under three classes A, B and C shown in Figure 5 (right half column) and only two classes A and B shown in Figure 6 (right half column). The y-axes of the all preceding graphs are cut at 0.6 for convenience, values greater than this are only found for low wind speeds which corresponds to minimal loadings on the wind turbines and are thus irrelevant for the results. It can be seen from these figures that the large scale turbulence intensity occur for higher wind speeds, and decreased continually, and most of the measured TI_u clusters are under the NTM limits, except some points, where a few of the measurements contain larger values than estimated by the NTM. It should be noted that all TI_u figures 5 and 6 at a wind speed equal to 15 m/s has average value TI_u = 0%.

The observations in figures-5 and 6 show that the pattern of the turbulence intensity at this site differ from the NTM and TI_u is found to be both lower and higher than the standard model. For the highly turbulent cases, it seems like the observed TI_u values generally are in the order of 50-60 % higher than the model for low wind speeds. Except for this deviation, there are a number of extreme cases when the turbulence intensity is much more severe than the modeled values, as indicated by the dots with high TI_u.

Regression is calculated, with the use of the least square method, and drawn as a pink color curve through all of the data points. In figures 5-6, the turbulence intensity (TI_{ave}) is plotted for speed interval of 1m/s in blue line (left column of these figures). The cyan line represents the 90th percentile of the observed turbulence intensity (TI_{90}). These average values can then be compared to the 50th and 90th percentiles (orange, black and green lines) respectively, under the NTM given by eq. 2 for small wind turbine (gives 2 classes) and the NTM given by eq's. 5, 6 for large wind turbine (gives 3 classes).

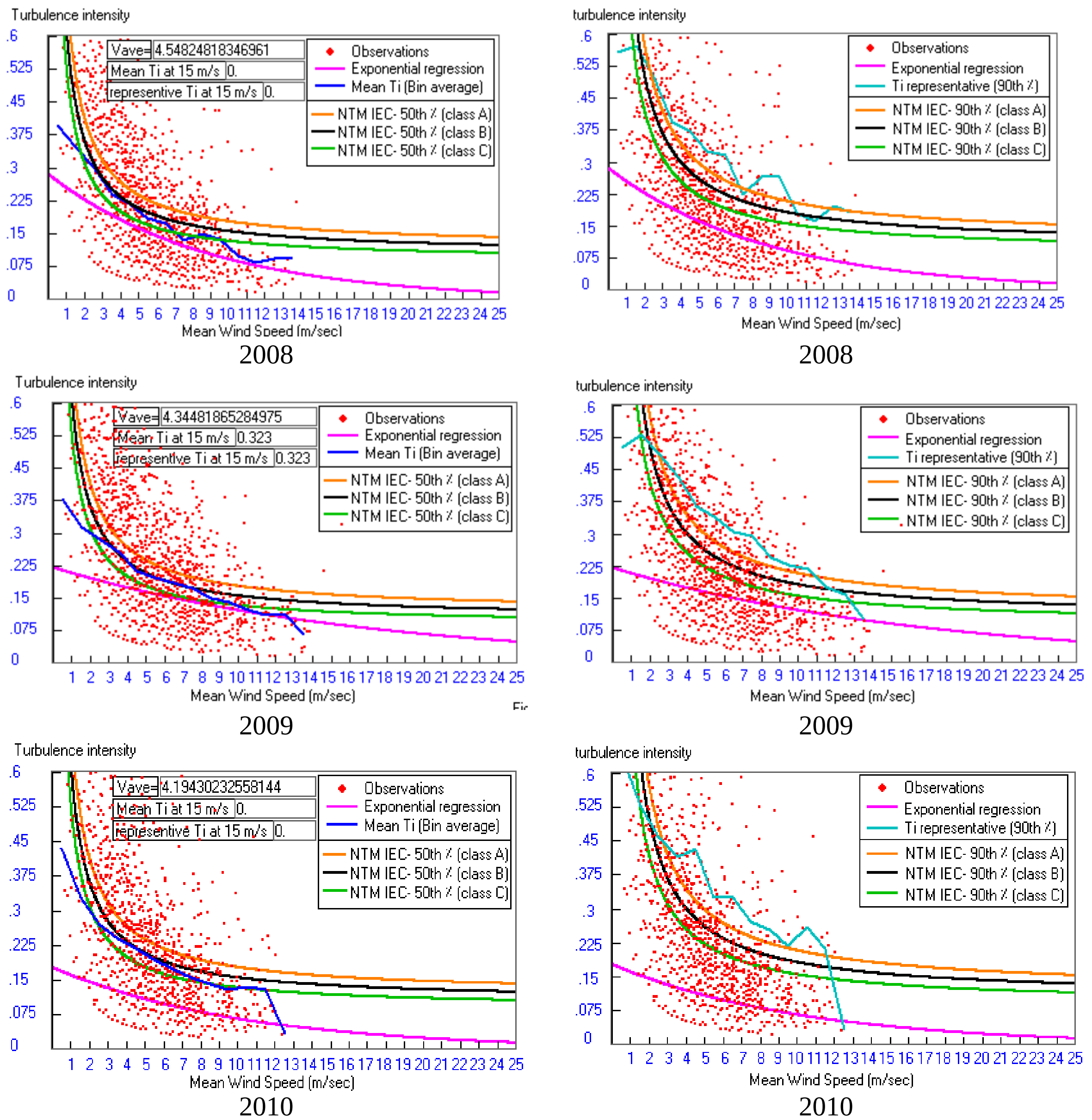

Figure 5- Turbulence intensity as a function of mean w. speed belongs to Nasiriyah site for large wind turbine.

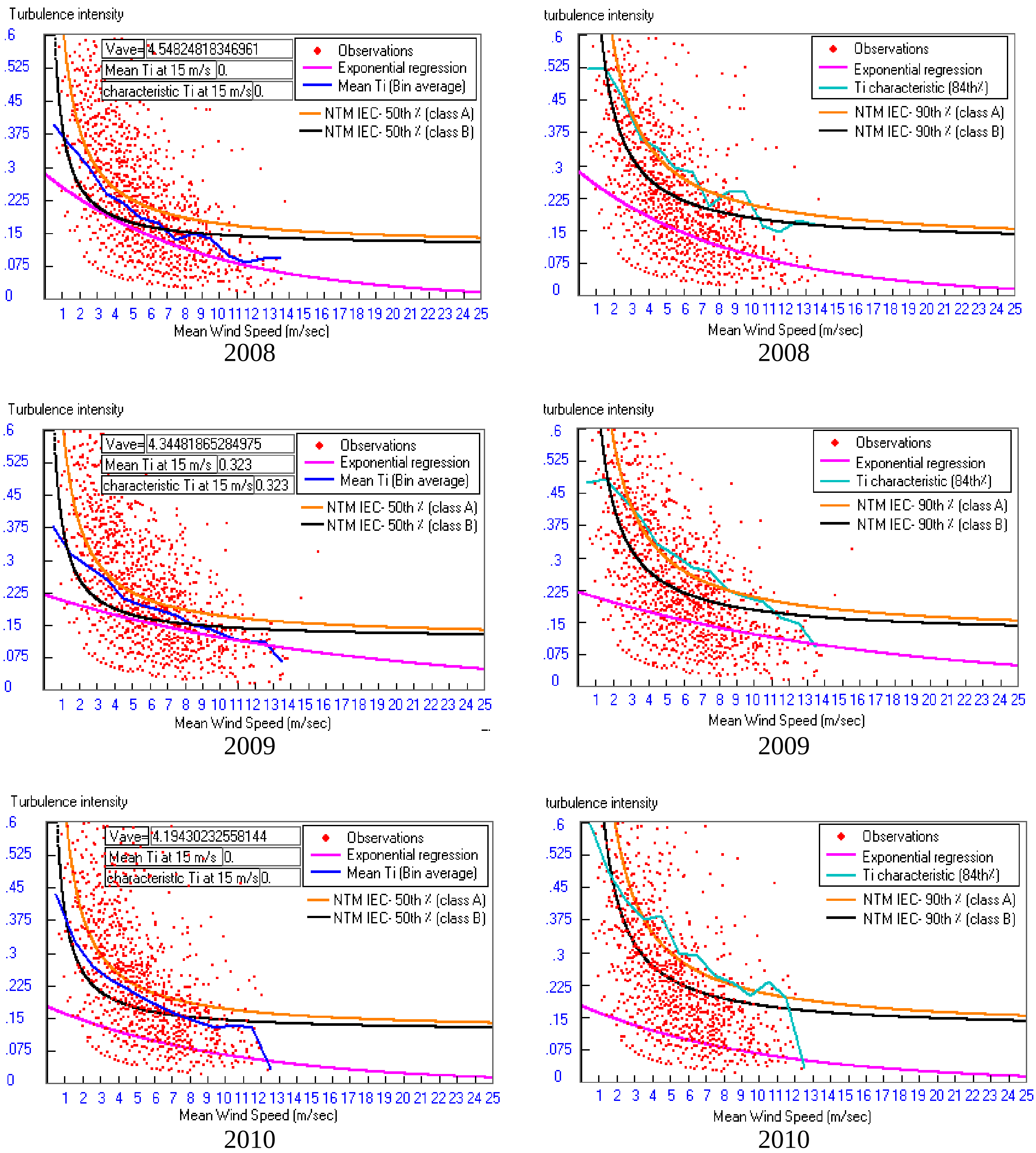

Figure 6- Turbulence intensity as a function of mean wind speed belongs to Nasiriyah site for small wind turbine.

iii. Distribution of turbulence intensity

In figure-7, the distribution of turbulence intensity, TI_u , is shown in yellow bars divided into intervals with bin size 5%. The left y-axis denotes the relative frequency of occurrence of TI_u within different intervals. The average turbulence intensity is also presented in these figures for the entire measuring period. The maximum value of x-axes is taken to be TI_u =120 % for convenience.

The highest frequency of turbulence intensity is in the range of 15-20%, as seen in Figure 7. Here, the observations have the shape of a Weibull distribution. The majority of the measurements are between 5-30% turbulence intensity with a peak at 15-20%. The cumulative frequency of turbulence is given on the right y-axis as a total number of elements.

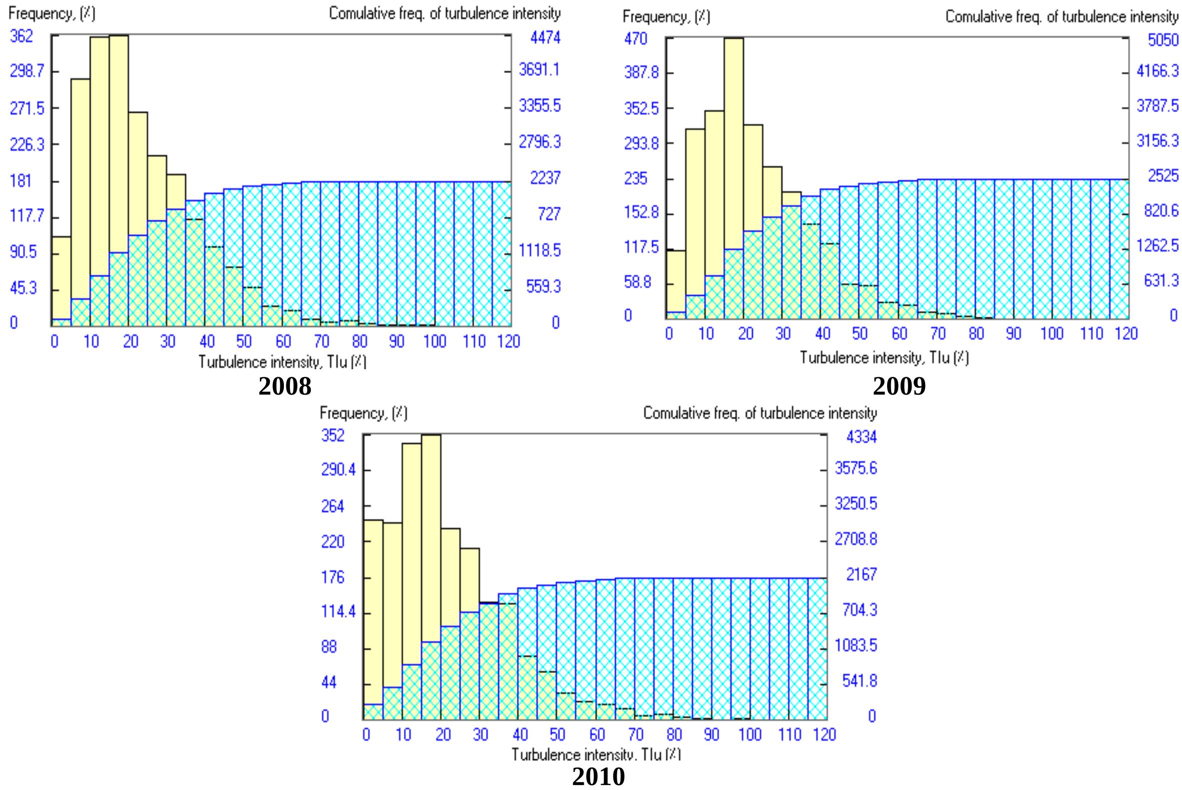

Figure 7- Frequency of turbulence intensity and its cumulative as a function of turbulence intensity belongs to Nasiriyah site for large and small wind turbine.

iv. Distribution of wind speeds

The distributions of TI_u as a function of mean wind speed can be seen in Figure 8, represents by green bars binned with intervals of 1m/s. The frequency of turbulence intensity is given on the y-axis as a total number of elements. The highest frequency of turbulence intensity occurs at a wind speed equal to 3m/s, figure-8.

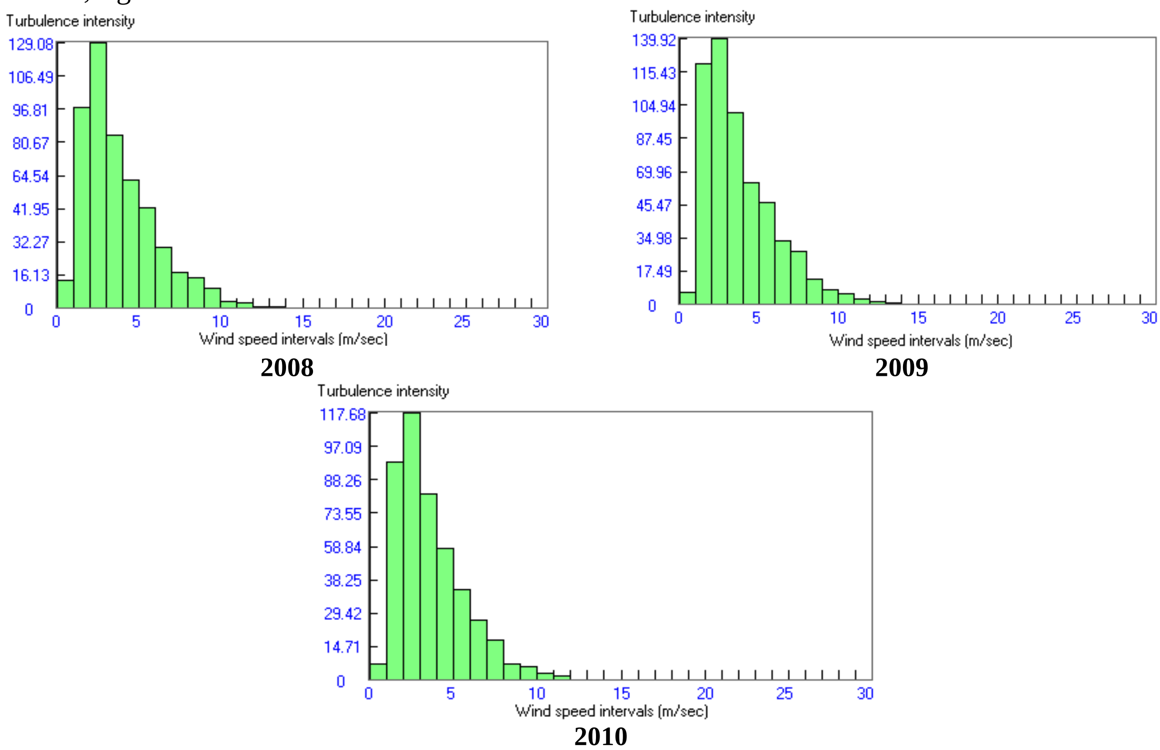

Figure 8- Turbulence intensity as a function of mean w. speed belongs to Nasiriyah site for large and small wind turbine.

7- Conclusion

Representative turbulence intensity (90th percentile) for Nasiriyah sit was calculated. The results were compared with the Standard (NTM) for LWTs and SWTs. From these results, it can be conclude that the observations from the site show that the flow and turbulence characteristics of terrain deviate slightly from what is estimated by the NTM, as it is defined for the standard LWT and SWT classes. The slow growth of σ_u with increasing wind speed (Figures 3 and 4), resulting in low turbulence intensities.

8- References

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