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TERRAIN COMPLEXITY INDEX: COMPARISONS BETWEEN IEC STANDARD DEFINITION AND NEW PROPOSAL

Pasquale Morelli[1], Andrea Vignaroli[2], Virginia Mangone[1]
[1]EDISON Energie Speciali S.p.A. [2]Windsim AS

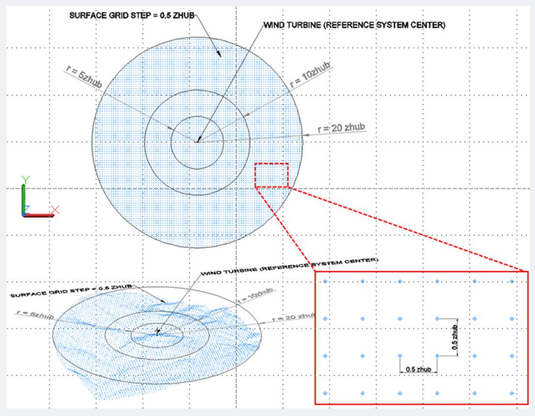
Motivation

The international Standard IEC 61400-1 3rd Ed Amd 1 (2010) 'Wind turbines – Part 1: Design requirements', which defines essential design requirements to ensure the engineering integrity of wind turbines, is today under revision. Special attention is given to sites in complex terrain, due to the fact that according to the standard, the topographical complexity can deeply affect the structure of turbulence, which could lead to more severe loads. However advanced wind measurements with sonic anemometers are necessary to estimate the turbulence structure and are usually barely available on sites. The standard therefore provides a simple procedure based on topographical data to assess if the terrain is complex and provides the relationship between complexity and turbulence structure. Chapter 11.2 aims to estimate the turbulence structure without any wind measurements. Most of the modifications introduced in the last version of the standard (2010) present inconsistencies.

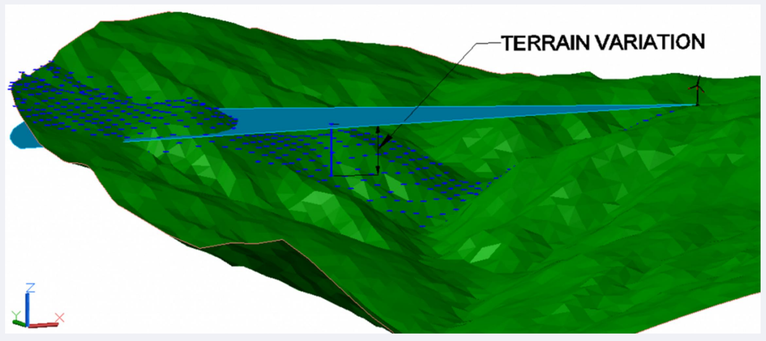
Tests based on the procedure of chapter 11.2 have been carried out on 170 different sites. The evaluations highlight where the weak points are and the need at least of the following improvements:
First the requirements on the grid resolution shall be improved. Second the effect of terrain complexity is direction dependent and should be assessed direction-wise even at small distances from the wind turbine and third the thresholds on terrain variation shall be harmonized. Forth sites in moderately complex terrain are not well represented as the energy threshold (15%) which defines the complexity index is too narrow and shall therefore be increased.
In the present work the complexity assessment according to IEC standard is evaluated and a revision is proposed.

IEC 61400-1 chapter 11.2

The sectorwise topographical complexity assessment asks to identify horizontal "circular sectors" of different radius and amplitudes centered in the point where the tower centerline crosses the terrain surface. One plane shall be defined for each horizontal "circular sector" as the plane that fits the portion of terrain corresponding to the "circular sector" and passes through the center.



For each "circular sector", both SLOPE and TERRAIN VARIATIONS are computed; Slope denotes the slopes of the lines contained in the fitted planes and corresponding to the mean line of each "wind sector". Accordingly, the terrain variation denotes the distances, along a vertical line, between the fitted planes and the terrain at the surface points.



Two checks are required for the 360° "wind sector" plus four checks for each of the twelve 30° "wind sector":

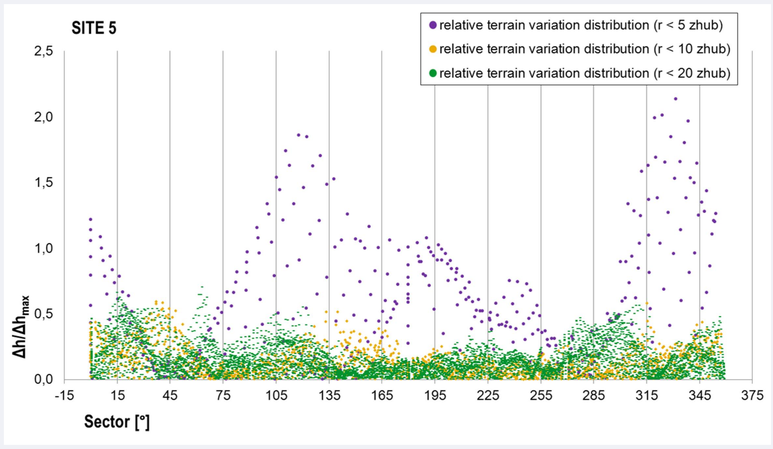
Distance range from wind turbine	Sector amplitude	Maximum slope of fitted plane	Maximum terrain variation
< 5 z_{hub}	360°	< 10°	0,3 z_{hub}
< 10 z_{hub}	30°		0,6 z_{hub}
< 20 z_{hub}	30°		1,2 z_{hub}

A "wind sector" is defined as complex if at least one of the checks fail. The terrain variation check criteria is considered fulfilled if the requisite fails over a surface less than a given size (i.e. a minimum number of points should fail).
A complexity index (ic) is then defined, such that ic = 0 when less than 5% of the energy comes from complex sectors, and ic = 1 when more than 15% of the energy comes from complex sectors. In between, ic varies linearly.

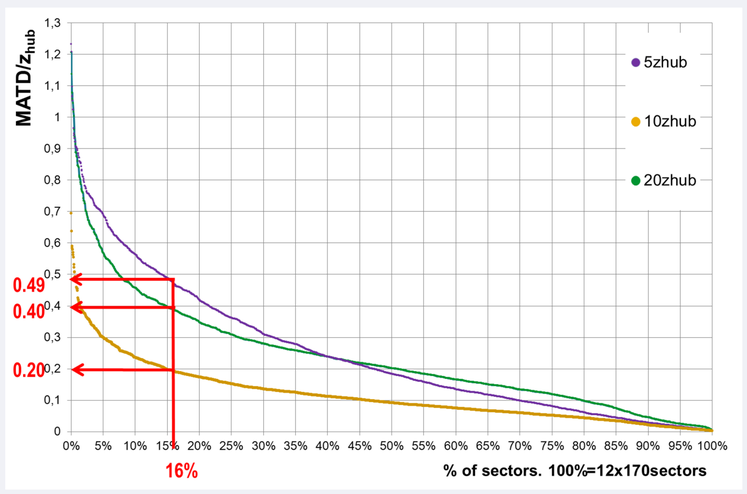
Proposed Review

170 sites have been tested in order to verify the methodology of the current procedure, taking into account flat, hilly and mountainous terrains. The following points shall be highlighted:

A. the resolution of surface grid required is too coarse. Assessments carried out with higher resolution led to rather different results. The maximum allowed grid resolution should be reduced to 0.5 z_{hub}.
B. one of the checks on terrain variation is dominant above the others: the $5z_{hub}$ check and doesn't take into account the frequency of the wind. The $5z_{hub}$ assessment should be done on the 30° circular sectors instead of the 360° .
C. even if $5z_{hub}$ check is carried out on 30° sectors, the check on terrain variations continues to be dominant above the others, as its threshold is too strict compared to the thresholds at $10z_{hub}$ and $20z_{hub}$. The thresholds on terrain variation should be harmonized.
The graph below shows the terrain variations compared to the thresholds.



Two options are possible, either the $5z_{hub}$ check could be made less restrictive, or the $10z_{hub}$ and $20z_{hub}$ could be made more restrictive. We suggest the second approach to be conservative.
With the $5Z_{hub}$ check based on 30° "circular sector", about 16% of the 170x12 "wind sectors" evaluated result to be complex.
To propose new thresholds, the Mean Absolute Terrain Deviation (MATD) has been considered through a statistical analysis. Graphs below plot the trends of **MATD/z_{hub}** for all the 170x12 "circular sectors".



In order to have almost the same percent (16%) the following thresholds result: $0.49Z_{hub}$ $0.20Z_{hub}$ $0.40Z_{hub}$ respectively for $5Z_{hub}$, $10Z_{hub}$, $20Z_{hub}$.

It could be noticed that the proposed MATD thresholds are proportional to the square root of the area of the "circular sectors" considered for plane fittings.

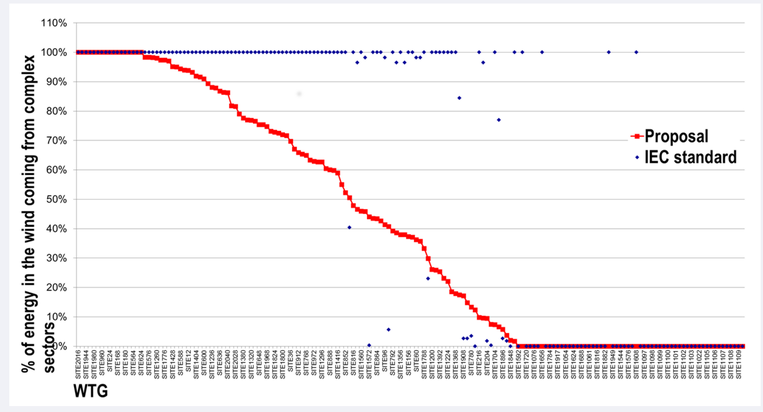
D. the minimum surface to consider the check fulfilled is a complicate criteria currently not well defined and is independent from the size of the circular sector evaluated. It is not necessary to fix a minimum surface if we take into account the maximum MATD instead of the maximum terrain variation.
E. ic assumes only two values: either 0 or 1, which means that it is not possible to distinguish between moderately complex and complex. Its definition should be review such that ic is = 1 when more than 50% (instead of 15%) of the energy comes from complex sectors.

The following table summarize the whole proposal:

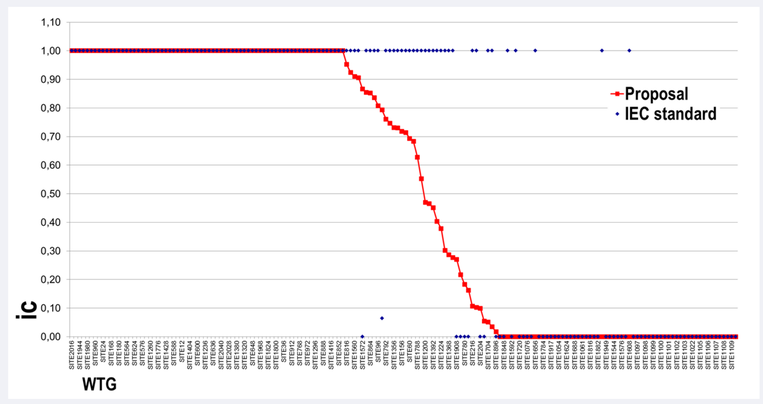
circular sector radius (centered on WTG)	circular sector amplitude for plane fitting	circular sector amplitude for check	maximum slope of fitted plane	maximum MATD
5 z_{hub}	360°	360°	10°	-
	360°	30°	-	0.49 z_{hub}
10 z_{hub}	30°	30°	10°	0.20 z_{hub}
20 z_{hub}	30°	30°	10°	0.40 z_{hub}

Results

The results of the site assessment according to the IEC standard and the proposal are reported in the following graphs.
The first graph plots the total energy in the wind coming from complex "circular sectors" for each site. The high number of blue points at 100% mainly depends on the issue B.



The second graph shows the ic trend. In 23% of the cases ic assumes values between 0 and 1.



Conclusion and Outlook

170 sites taking into account flat, hilly and mountainous terrains have been tested to evaluate the IEC standard procedure. we propose minor modifications which improve the complexity assessment methodology.
The proposal allows to better represent the topographical differences defining various levels of complexity over a wide spectrum of sites.
Thresholds (both slope and MATD) shall be further tested on more sites, comparing the measured turbulence structure with the one estimated from topographical complexity.

References

1. IEC 61400-1, 3rd edition ,Design Requirements, 2005
2. IEC 61400-1 amd1, 3rd edition, Design Requirements, 2010