IEC 61400-1

Edition 3.0 2010-10

INTERNATIONAL STANDARD

NORME INTERNATIONALE

AMENDMENT 1
AMENDEMENT 1

Wind turbines –
Part 1: Design requirements

Eoliennes –
Partie 1: Exigences de conception

IEC 61400-1:2005-08/AMD1:2010-10(en-fr)

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FOREWORD

This amendment has been prepared by IEC technical committee 88: Wind turbines.

This bilingual version (2015-02) corresponds to the English version, published in 2010-10.

The text of this amendment is based on the following documents:

FDIS	Report on voting
88/374/FDIS	88/378/RVD

Full information on the voting for the approval of this amendment can be found in the report on voting indicated in the above table.

The French version of this amendment has not been voted upon.

The committee has decided that the contents of this amendment and the base publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

2 Normative references

Replace the existing list of normative references by the following new list:

IEC 60204-1, *Safety of machinery – Electrical equipment of machines – Part 1: General requirements*

IEC 60204-11, *Safety of machinery – Electrical equipment of machines – Part 11: Requirements for HV equipment for voltages above 1 000 V a.c. or 1 500 V d.c. and not exceeding 36 kV*

IEC 60364 (all parts), *Low-voltage electrical installations*

IEC 60364-5-54, *Electrical installations of buildings – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements, protective conductors and protective bonding conductors*

IEC 60721-2-1, *Classification of environmental conditions – Part 2: Environmental conditions appearing in nature – Temperature and humidity*

IEC 61000-6-1, *Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity for industrial environments*

IEC 61000-6-4, *Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments*

IEC 61400-2, *Wind turbines – Part 2: Design requirements for small wind turbines*

IEC 61400-21, *Wind turbines – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines*

IEC 61400-24, *Wind turbines – Part 24: Lightning protection*

IEC 62305-3, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

IEC 62305-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

ISO 76:2006, *Rolling bearings – Static load ratings*

ISO 281, *Rolling bearings – Dynamic load ratings and rating life*

ISO 2394:1998, *General principles on reliability for structures*

ISO 2533:1975, *Standard atmosphere*

ISO 4354, *Wind actions on structures*

ISO 6336-2, *Calculation of load capacity of spur and helical gears – Part 2: Calculation of surface durability (pitting)*

ISO 6336-3:2006, *Calculation of load capacity of spur and helical gears – Part 3: Calculation of tooth bending strength*

ISO 81400-4, *Wind turbines – Part 4: Design and specification of gearboxes*

3 Terms and definitions

3.26 – limit state

Replace ISO 2394 *by* 2.2.9 of ISO 2394.

3.55 – ultimate limit state

Replace ISO 2394 *by* 2.2.10 of ISO 2394.

4 Symbols and abbreviated terms

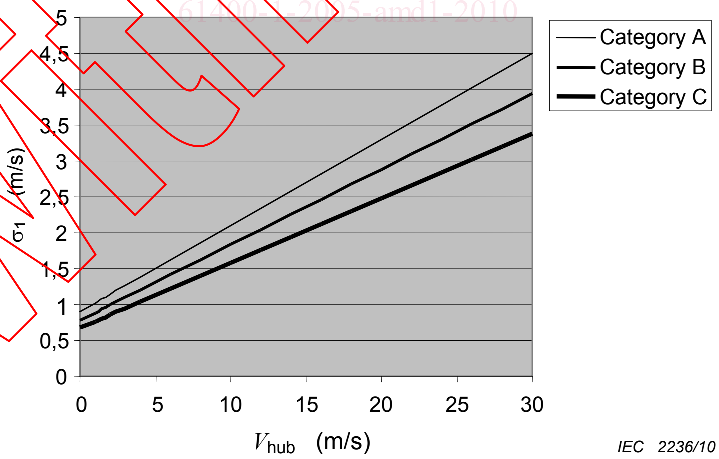
4.1 Symbols and units

Switch the definitions of σ_2 and σ_3. The vertical wind velocity standard deviation should be σ_3, not σ_2.

6 External conditions

6.3.1.3 Normal turbulence model (NTM)

Replace the existing Figures 1a and 1b by the following new figures:



IEC 2236/10

Figure 1a –Turbulence standard deviation for the normal turbulence model (NTM)

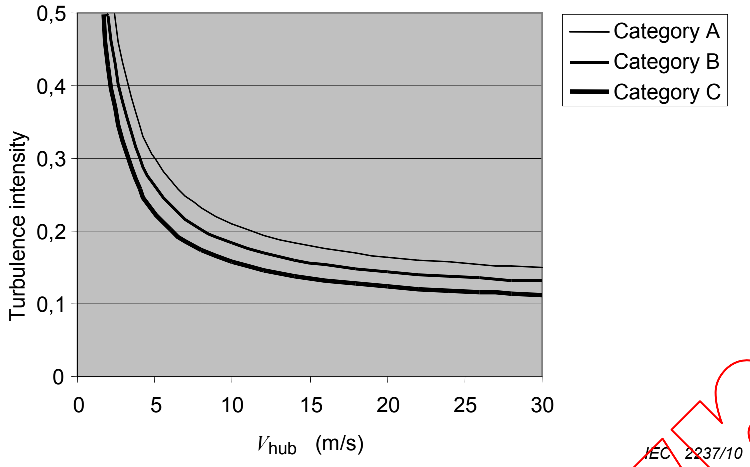


Figure 1b – Turbulence intensity for the normal turbulence model (NTM)

6.3.2.6 Extreme wind shear (EWS)

Replace the number 2,5 in equations (26) and (27) to 2,5 [m/s]. (The number 2,5 in equations (26) and (27) is not dimensionless.)

7 Structural design

7.4.2 Power production plus occurrence of fault or loss of electrical network connection (DLC 2.1 – 2.4)

Add, as 2nd paragraph, the following new text:

As an alternative to the specification of DLC 2.3 above and in Table 2, DLC 2.3 may instead be considered as a normal event (i.e. a partial safety factor for load of 1,35) to be analyzed using stochastic wind simulations (NTM - $V_{in}<V_{hub}<V_{out}$) combined with an internal or external electrical system fault (including loss of electrical network connection). In this case, 12 response simulations shall be carried out for each considered mean wind speed. For each response simulation, the extreme response after the electrical fault has occurred is sampled. The fault must be introduced after the effect of initial conditions has become negligible. For each mean wind speed, a nominal extreme response is evaluated as the mean of the 12 sampled extreme responses plus three times the standard deviation of the 12 samples. The characteristic response value for DLC 2.3 is determined as the extreme value among the nominal extreme responses.

7.5 Load calculations

Add, after second paragraph, the following new text:

When turbulent winds are used for dynamic simulations, attention should be given to the grid resolution regarding the spatial[1] and time resolution.

1 Concerning the spatial resolution, the maximum distance between adjacent points should be smaller than 25 % of $\Lambda 1$ (Equation (5)) and no larger than 15 % of the rotor diameter. This distance is meant to be the diagonal distance between points in each grid cell defined by four points. In the case of a non-uniform grid, an average value over the rotor surface of the distance between grid points can be considered as the representative spatial resolution, but this distance should always decrease towards the blade tip.

Replace the last paragraph by the following new text:

Ultimate load components may also be combined in a conservative manner assuming the extreme component values occur simultaneously. In case this option is pursued, both minimum and maximum extreme component values shall be applied in all possible combinations to avoid introducing non-conservatism.

Guidance for the derivation of extreme design loads from contemporaneous loads taken from a number of stochastic realisations is given in Annex H.

7.6.1.2 Partial safety factor for consequence of failure and component classes

Add, after the bullets defining the component classes, the following new text:

The consequences of failure factor shall be included in the test load when performing tests as for example full scale blade testing.

7.6.2 Ultimate strength analysis

Replace equation (31) by the following new equation:

$$\gamma_f F_k \leq \frac{1}{\gamma_n} \cdot \frac{1}{\gamma_m} f_k \qquad (31)$$

Add the following new paragraph after equation (31):

Note that γ_n is a consequence of failure factor and shall not be treated as a safety factor on materials.

Delete the last sentence in 5th paragraph ("For guidance see Annex F") and insert, after the 5th paragraph, the following two paragraphs:

Data used in extrapolation methods shall be extracted from time series of turbine simulations of at least 10 min in length over the operating range of the turbine for DLC 1.1. A minimum of 15 simulations is required for each wind speed from (V_{rated} – 2 m/s) to cut-out and six simulations are required for each wind speed below (V_{rated} – 2 m/s). When extracting data, the designer must consider the effect of independence between peaks on the extrapolation and minimize dependence when possible. The designer shall aggregate data and probability distributions to form a consistent long-term distribution. To ensure stable estimation of long-term loads, a convergence criterion shall be applied to a probability fractile less than the mode of the data for either the short-term or long-term exceedance distributions. For guidance, see Annex F.

The characteristic value for blade root in-plane and out-of-plane moments and tip deflection may be determined by a simplified procedure[2]. The characteristic value may then be determined by calculating the mean of the extremes for each 10-min bin and using the largest value, multiplied by an extrapolation factor of 1,5, while maintaining the partial load factor for statistical load extrapolation, see Table 3.

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2 This approach is considered conservative for 3-bladed upwind wind turbines. Caution should be exercised for other wind turbine concepts.

7.6.2.1 Partial safety factor for loads

Replace the existing formula in the footnote of Table 3 by the following new formula:

$$\varsigma = \begin{cases} 1 - \left| \dfrac{F_{\text{gravity}}}{F_{\text{k}}} \right|; & \left| F_{\text{gravity}} \right| \le \left| F_{\text{k}} \right| \\ 0; & \left| F_{\text{gravity}} \right| > \left| F_{\text{k}} \right| \end{cases}$$

Add the following new text after Table 3:

The approach in 7.6.1.1, where the partial safety factor for loads is applied to the load response, assumes that a proper representation of the dynamic response is of prime concern. For foundations or where a proper representation of non-linear material behaviour or geometrical non-linearities or both are of primary concern, the design load response S_d shall be obtained from a structural analysis for the combination of the design loads F_d, where the design load is obtained by multiplication of the characteristic loads F_k by the specified partial load factor γ_f for favourable and unfavourable loads,

$$F_d = \gamma_f F_k$$

The load responses in the tower at the interface (shear forces and bending moments) factored with γ_f from Table 3 shall be applied as boundary conditions.

For gravity foundations, the limit states considering overall stability (rigid body motion with no failure in soil) and bearing capacity of soil and foundation shall be regarded and calculated according to a recognized standard. In general, a partial safety factor of γ_f = 1,1 for unfavourable permanent loads and γ_f = 0,9 for favourable permanent loads shall be applied for foundation load, backfilling and buoyancy. If it can be demonstrated by respective quality management and surveillance that the foundation material densities specified in the design documentation are met on site, a partial safety factor for permanent foundation load γ_f = 1,0 can be used for the limit states regarding bearing capacity of soil and foundation. If buoyancy is calculated equal to a terrain water level, a partial safety factor for buoyancy γ_f = 1,0 can be applied.

Alternatively, the check of capacity of soil and foundation can be based on a partial safety factor γ_f = 1,0 for both favourable and unfavourable permanent loads and the check of overall stability can be based on a partial safety factor of γ_f = 1,1 for unfavourable permanent loads and γ_f = 0,9 for favourable permanent loads, using in all cases conservative estimates of weights or densities defined as 5 % / 95 % fractiles. The lower fractile is to be used when the load is favourable. Otherwise, the upper fractile is to be used.

7.6.5 Critical deflection analysis

Replace the existing text by the following new text:

7.6.5.1 General

It shall be verified that no deflections affecting structural integrity occur in the design conditions detailed in Table 2.

The maximum elastic deflection in the unfavourable direction shall be determined for the load cases detailed in Table 2 using the characteristic loads. The resulting deflection is then multiplied by the combined partial safety factor for loads, materials and consequences of failure.

- Partial safety factor for loads

The values of γ_f shall be chosen from Table 3.

- Partial safety factor for the elastic properties of materials

The value of γ_m shall be 1,1 except when the elastic properties of the component in question have been determined by testing and monitoring in which case it may be reduced. Particular attention shall be paid to geometrical uncertainties and the accuracy of the deflection calculation method.

- Partial safety factor for consequences of failure

Component class 1: γ_n = 1,0

Component class 2: γ_n = 1,0

Component class 3: γ_n = 1,3.

The elastic deflection shall then be added to the un-deflected position in the most unfavourable direction and the resulting position compared to the requirement for non-interference.

7.6.5.2 Blade (tip) deflection

One of the most important considerations is to verify that no mechanical interference between blade and tower will occur.

In general, blade deflections have to be calculated for the ultimate load cases as well as for the fatigue load cases. The deflections caused by the ultimate load cases can be calculated based on beam models, FE models or the like. All relevant load cases from Table 2 have to be taken into account with the relevant partial load safety factors.

Moreover, for load case 1.1 extrapolation of tip deflection is mandatory according to 7.4.1. Here direct dynamic deflection analysis can be used. The exceedance probability in the most unfavourable direction shall be the same for the characteristic deflection as for the characteristic load. The characteristic deflection is then to be multiplied by the combined safety factor for loads, materials and consequences of failure and be added to the un-deflected position in the most unfavourable direction and the resulting position compared to the requirement for non-interference.

9 Mechanical systems

9.4 Main gearbox

Replace the existing text by the following new text:

The main gearbox shall be designed according to ISO 81400-4, until a similar document is published in the IEC 61400 series.

9.5 Yaw system

Replace the second paragraph by the following new text:

Any motors shall comply with relevant parts of Clause 10.

Non-redundant parts of the gear system such as the final yaw gear shall be considered as component class 2. When multiple yaw drives ensure sufficient redundancy in the yaw gear system, and easy replacement is possible, the reduction gearbox and the final drive pinion may be considered to be in component class 1.

The safety against pitting shall be determined in accordance with ISO 6336-2. The application of the upper limit curve (1) for life factor Z_{NT}, which allows limited pitting, is permissible. Sufficient tooth bending strength shall be proven in accordance with ISO 6336-3. The reverse bending loads on gear teeth shall be considered in accordance with ISO 6336-3 Annex B. Minimum values for S_F and S_H are specified in Table 5. These values must be achieved by using characteristic loads F_k Hence they include the partial safety factor for consequences, γ_n, materials, γ_m and loads, γ_f.

Table 5 – Minimum required safety factor S_H and S_F for the yaw gear system

	Component class 1	Component class 2
Surface durability (pitting)	$s_H \geq 1,0$	$s_H \geq 1,1$
Tooth bending fatigue strength	$s_F \geq 1,1$	$s_F \geq 1,25$
Static bending strength	$s_F \geq 1,0$	$s_F \geq 1,2$

Lower safety factors may be applicable in cases where efficient monitoring is implemented. If safety factors below 1,0 are applied, then the maintenance manual must reflect anticipated replacement intervals.

10 Electrical system

10.5 Earth system

Replace, in the first paragraph, IEC 61024-1 *by* IEC 62305-3.

10.6 Lightning protection

Replace IEC 61024-1 *by* IEC 62305-3.

10.9 Protection against lightning electromagnetic fields

Replace, in the first paragraph, IEC 61312-1 *by* IEC 62305-4.

11 Assessment of a wind turbine for site-specific conditions

11.2 Assessment of the topographical complexity of a site

Replace the text of this subclause by the following new text:

The complexity of the site is characterised by the slope of the terrain and variations of the terrain topography from a plane.

To obtain the slope of the terrain, planes are defined that fit the terrain within specific distances and sector amplitudes for all wind direction sectors around the wind turbine and pass through the tower base. The slope, used in Table 4, denotes the slopes of the different mean lines of sectors passing through the tower bases and contained in the fitted planes. Accordingly, the terrain variation from the fitted plane denotes the distance, along a vertical line, between the fitted plane and the terrain at the surface points.

Table 4 – Terrain complexity indicators

Distance range from wind turbine	Sector amplitude	Maximum slope of fitted plane	Maximum terrain variation[3]
< 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}

The resolution of surface grids used for terrain complexity assessment must not exceed the smallest of 1,5 z_{hub} and 100 m.

The site shall be considered complex, if 15 % of the energy in the wind comes from sectors that fail to conform to the criteria in Table 4 and homogeneous, if less than 5 % of the energy in the wind comes from sectors that fail to conform.

A complexity index i_c is defined, such that i_c = 0 when less than 5 % of the energy comes from complex sectors, and i_c = 1 when more than 15 % of the energy comes from complex sectors. In between, i_c varies linearly.

11.4 Assessment of wake effects from neighbouring wind turbines

Add the following new text after the 3rd paragraph:

Generally, the effective turbulence for fatigue and various ultimate loads cannot be assumed to be the same.

Delete the 4th paragraph to the end of the subclause.

11.9 Assessment of structural integrity by reference to wind data

Replace the existing footnote 18 by the following new footnote:

[18] The effect of complex terrain may be included by additional multiplication with a turbulence structure correction parameter C_{CT} defined as

$$C_{CT} = \frac{\sqrt{1 + (\hat{\sigma}_2 / \hat{\sigma}_1)^2 + (\hat{\sigma}_3 / \hat{\sigma}_1)^2}}{1{,}375}$$

where ratios of the estimated standard deviations, $\hat{\sigma}_i$, correspond to hub height values. Where there are no site data for the components of turbulence and the terrain is complex, results of modelling or C_{CT} = 1+0,15 i_c, where i_c is the complexity index defined in Subclause 11.2, may be used.

Replace the 5th paragraph to the end of the subclause by the following new text:

An adequate assessment of wake effects[4] can be performed by verifying that the turbulence standard deviation σ_1 from the normal turbulence model is greater or equal to the estimated 90 % fractile of the turbulence standard deviation (including both ambient and wake

3 The check criteria is considered fulfilled if the requisite fails over a surface less than 5 z_{hub}^2.

4 This approach can also be used for the assessment of sector-wise varying turbulence, alone or in combination with wake turbulence. The standard deviation $\hat{\sigma}_{\sigma}$ of $\hat{\sigma}$ may be determined as the average of the sector-wise values.

turbulence) between the wind speeds 0,2 V_{ref} and 0,4 V_{ref} (or when the turbine properties are known, between 0,6 V_r and V_{out}), i.e.:

$$\sigma_1 \geq I_{eff} \cdot V_{hub} \tag{35}$$

Guidance for calculating I_{eff} can be found in Annex D.

Furthermore, it shall be demonstrated that the site specific horizontal shear due to partial wakes does not exceed EWS in 6.3.2.6 and that the site specific extreme turbulence[5], including the wake effects, does not exceed the ETM model in 6.3.2.3. For determination of the site specific turbulence, the site specific conditions, the frequency of the wake situations and wind farm layout shall be accounted for.

11.10 Assessment of structural integrity by load calculations with reference to site specific conditions

Replace the 2nd paragraph to the end of the subclause by the following new text:

Where there are no site data for the components of turbulence and the terrain is complex, it shall be assumed that the lateral and upward turbulence standard deviations relative to the longitudinal component are equal to 1,0 and 0,7, respectively.

In the case of wake effects, it shall be verified that structural integrity is not compromised for ultimate and fatigue limit states. For fatigue limit state in DLC 1.2 σ_1 in the normal turbulence, model is replaced by an appropriate wake turbulence model, e.g. I_{eff}, found in Annex D.

For ultimate limit state analysis, DLC 1.1 or DLC 1.3, as well as DLC 1.5, shall be applied with site specific conditions including wake effects represented by appropriate models. NTM for ULS loads can be set to characteristic ambient turbulence inside large farms as defined in Annex D, Equation (D.4).

Since for fatigue load calculations, I_{eff} as defined in Annex D depends on the Wöhler curve exponent m of the material of the considered component, the loads on structural components with other material properties shall either be recalculated or assessed with the appropriate value of m.

Annex B – Turbulence models

B.1 Mann (1994) uniform shear turbulence model

Replace the equation defining C_2 by the following new equation:

$$C_2 = \frac{k_2 k_0^2}{\left(k_1^2 + k_2^2\right)^{3/2}} \arctan\left(\frac{\beta(k) k_1 \sqrt{k_1^2 + k_2^2}}{k_0^2 - \left(k_3 + \beta(k) k_1\right) k_1 \beta(k)}\right)$$

5 The site specific extreme turbulence may be represented by the maximum centre wake turbulence in the most severe direction.

Annex D – Wake and wind farm turbulence

Replace the existing text of Annex D by the following new text:

D.1 Wake effects

Wake effects from neighbouring wind turbines may be taken into account during normal operation for fatigue calculation by an effective turbulence intensity I_{eff}, Frandsen (2007). The effective turbulence intensity – conditioned on hub height mean wind speed - may be defined as

$$I_{\text{eff}}(V_{\text{hub}}) = \left\{ \int_0^{2\pi} p(\theta|V_{\text{hub}}) I^m(\theta|V_{\text{hub}}) d\theta \right\}^{\frac{1}{m}} \qquad \text{(D.1)}$$

where

V_{hub} is the wind speed at hub height;

p is the probability density function of wind direction;

I is the turbulence intensity of the combined ambient and wake flows from wind direction θ, and

m is the Wöhler (SN-curve) exponent for the considered material.

In the following, a uniform distribution $p(\theta|V_{hub})$ is assumed. It is also acceptable to adjust the formulas for other than uniform distribution[6]. No reduction in mean wind speed inside the wind farm shall be assumed.

If $\min\{d_i\} \geq 10\,D$:

$$I_{\text{eff}} = \frac{\hat{\sigma}_c}{V_{\text{hub}}} \qquad \text{(D.2)}$$

If $\min\{d_i\} < 10\,D$:

$$I_{\text{eff}} = \frac{\hat{\sigma}_{\text{eff}}}{V_{\text{hub}}} = \frac{1}{V_{\text{hub}}}\left[(1 - N\,p_{\text{w}})\hat{\sigma}_{\text{c}}^m + p_{\text{w}} \sum_{i=1}^{N} \hat{\sigma}_{\text{T}}^m(d_i)\right]^{\frac{1}{m}} ;\ p_{\text{w}} = 0{,}06 \qquad \text{(D.3)}$$

where

$\hat{\sigma}_c = \hat{\sigma} + 1{,}28\hat{\sigma}_\sigma$ is the characteristic ambient turbulence standard deviation;

$\hat{\sigma}$ is the estimated ambient turbulence standard deviation;

[6] In the case of non-uniform distribution or non-grid wind farm layout, the formula must be modified accordingly, maintaining the concept implied in the more general formula D.1, it must be taken into consideration for each neighbor affecting wind turbine, the sector disturbed and their associated probability of occurrence conditioned on hub height mean wind speed.

$\hat{\sigma}_{\sigma}$ is the estimated standard deviation of the ambient turbulence standard deviation;

$\hat{\sigma}_{\mathrm{T}} = \sqrt{\dfrac{V_{\mathrm{hub}}^2}{\left(1{,}5 + \dfrac{0{,}8 d_{\mathrm{i}}}{\sqrt{C_{\mathrm{T}}}}\right)^2} + \hat{\sigma}_{\mathrm{c}}^2}$ is the characteristic value of the maximum center-wake, hub height turbulence standard deviation ($\hat{\sigma}_c$ shall not account for farm generated ambient turbulence);

C_{T} is the characteristic value of the wind turbine thrust coefficient for the corresponding hub height wind velocity. If the thrust coefficient for the neighbouring wind turbines are not known, a generic value C_{T} = 7 c /V_{hub} can be used;

d_{i} is the distance, normalised by rotor diameter, to neighbouring wind turbine no. i;

c is a constant equal to 1 m/s;

I_{eff} is the effective turbulence intensity;

N is the number of neighbouring wind turbines; and

m is the Wöhler curve exponent corresponding to the material of the considered structural component.

Wake effects from wind turbines “hidden” behind other machines need not be considered, for example in a row, only wakes from the two units closest to the machine in question are to be taken into account. Dependent on wind farm configuration, the number of nearest wind turbines to be included in the calculation of I_{eff} is as given in Table D.1.

The wind farm configurations are illustrated in Figure D.1 for the case “Inside a wind farm with more than 2 rows”.

Table D.1 – Number of nearest wind turbine to be considered

Wind farm configuration	N
2 wind turbines	1
1 row	2
2 rows	5
Inside a wind farm with more than 2 rows	8

Inside large wind farms, wind turbines tend to generate their own ambient turbulence. Thus, when

a) the number of wind turbines from the considered unit to the “edge” of the wind farm is more than 5, or

b) the spacing in the rows perpendicular to the predominant wind direction is less than $3D$,

then the following characteristic ambient turbulence shall be assumed instead of $\hat{\sigma}_c$ except in the expression for $\hat{\sigma}_{\mathrm{T}}$:

$$\hat{\sigma}_c' = \tfrac{1}{2}\left(\sqrt{\hat{\sigma}_w^2 + \hat{\sigma}^2} + \hat{\sigma}\right) + 1{,}28\hat{\sigma}_{\sigma} \qquad \text{(D.4)}$$

where

$$\hat{\sigma}_{\mathrm{w}} = \frac{0{,}36\, V_{\mathrm{hub}}}{1 + 0{,}2\sqrt{d_{\mathrm{r}} d_{\mathrm{f}} / C_{\mathrm{T}}}} \qquad \text{(D.5)}$$