Introduction to the IEC 61400-1 standard

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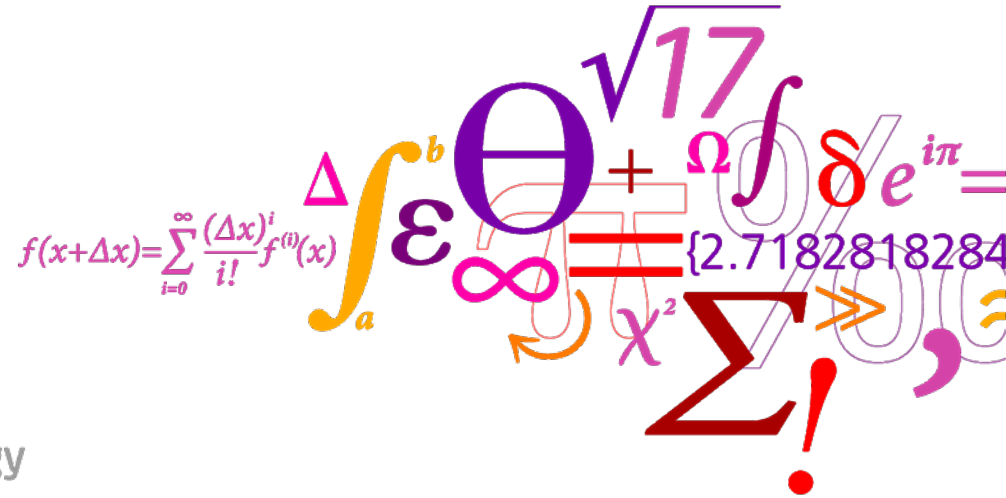
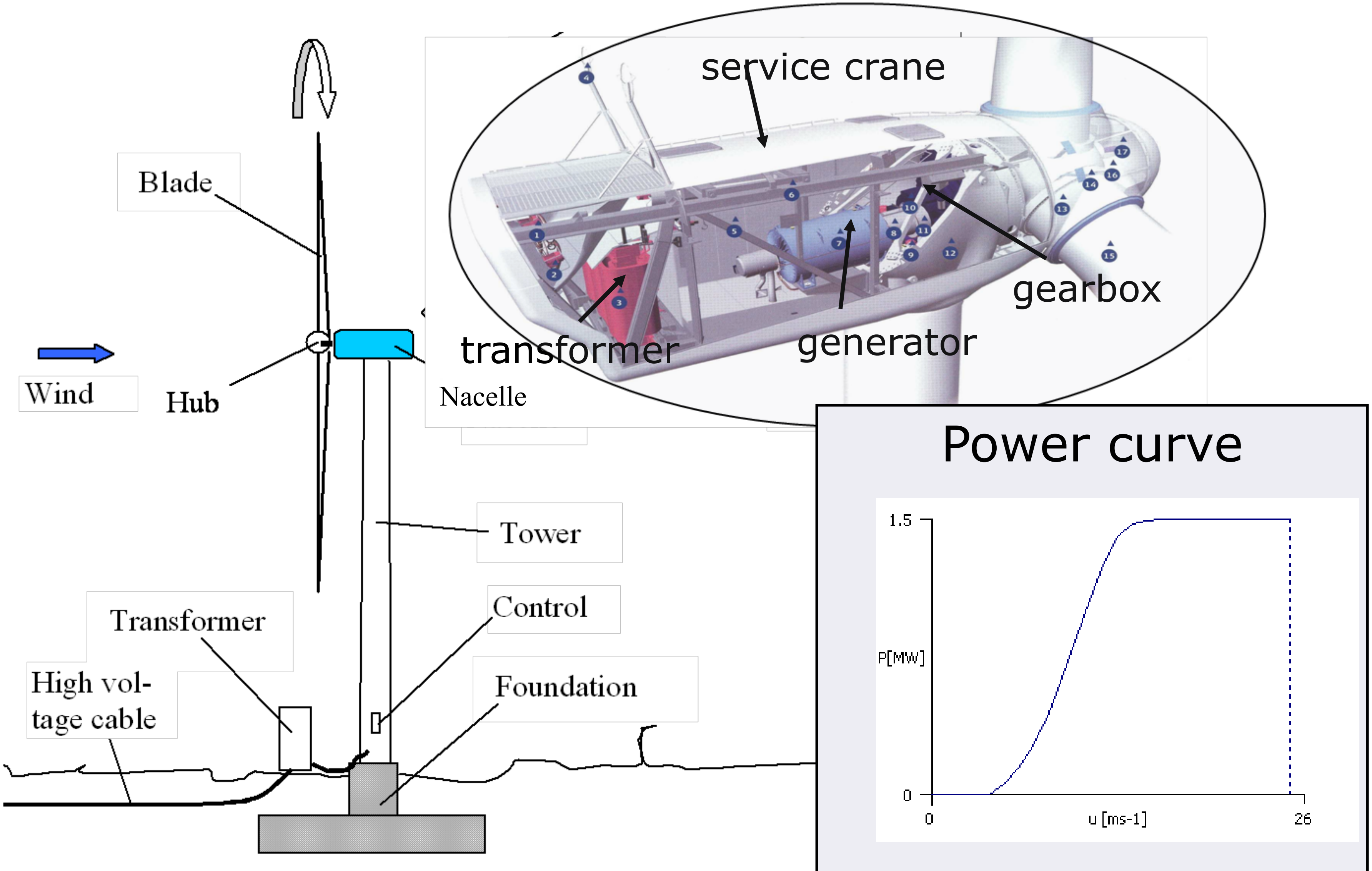


IEC or ISO? (Electric component, machine or building – or – a wind turbine)

Wind turbine generator system ~ Wind turbine structure

The wind turbine – a complex system



IEC TC88: IEC 61400 standards series

- IEC 61400-1 Design requirements
- IEC 61400-2 Small wind turbines
- IEC 61400-3 Design requirements for offshore wind turbines
- *IEC 61400-4 Gears for wind turbines*
- *IEC 61400-(5) Wind Turbine Rotor Blades*
- IEC 61400-11, Acoustic noise measurement techniques
- IEC 61400-12-1 Power performance measurements
- IEC 61400-13 Measurement of mechanical loads
- IEC 61400-14 Declaration of sound power level and tonality
- IEC 61400-21 Measurement of power quality characteristics
- *IEC 61400-22 Conformity Testing and Certification of wind turbines*
- IEC 61400-23 TR Full scale structural blade testing
- IEC 61400-24 TR Lightning protection
- IEC 61400-25-(1-6) Communication
- *IEC 61400-26 TS Availability*
- *IEC 61400-27 Electrical simulation models for wind power generation*

- *IEC 60076-16: Transformers for wind turbines applications*

IEC61400-1: 2005 Wind Turbines – Design Requirements

Principles

"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"

Content

- External conditions (e.g. wind) – **Wind turbine classes**
- Structural design (e.g. load cases and methods)
- Control and protection system (what to consider)
- Mechanical system (e.g. yaw, brakes)
- Electrical system (e.g. lightning)
- Site assessment
- Assembly, installation, erection
- Commisioning, operation, maintenance

IEC61400-1: 2005 Wind Turbines – Design Requirements - Amendment

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

Partial safety factor for consequence of failure and component classes

Ultimate strength analysis

Partial safety factor for load (*gravity foundations*)

Critical deflection analysis

- Blade (tip) deflection

Gearbox

Yaw system

Assessment of the topographical complexity of a site

Asssessment of wake effects from neighbouring wind turbines

Assessment of structural integrity by reference to wind data

Annex (Informative) Wake and wind farm turbulence.

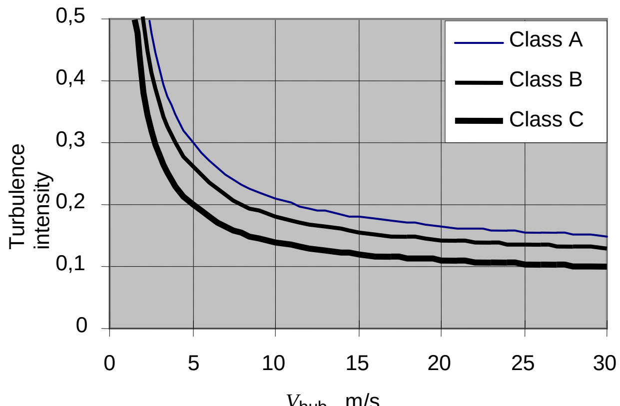
Annex (Informative) Statistical extrapolation of loads for ultimate strength analysis.

Annex (Informative) Contemporaneous loads.

Wind turbine classes

- Wind turbine classes are defined in 61400-1 and intended to cover most possible sites

Wind turbine class	I	II	III	S
V_{ref} (m/s)	50	42,5	37.5	Values specified by the designer
A I_{ref} (-)	0,16			
B I_{ref} (-)	0,14			
C I_{ref} (-)	0,12			



$$V_{ave} = 0,2\, V_{ref}$$

$$V(z) = V_{hub}\left(z/z_{hub}\right)^{\alpha}; \quad \alpha = 0,2$$

Wind in IEC 61400-1

Rayleigh distributed wind speed:

$$P_R(V_{hub}) = 1 - \exp\left[-\pi\left(V_{hub} / 2V_{ave}\right)^2\right]$$

$$V_{ave} = 0{,}2\, V_{ref}$$

Power law wind profile:

$$V(z) = V_{hub}\left(z / z_{hub}\right)^{\alpha}$$

$$\alpha = 0{,}2$$

Extreme wind speed model:

Steady:

$$V_{e50}(z) = 1{,}4\, V_{ref}\left(z / z_{hub}\right)^{0{,}11}$$

$$V_{e1}(z) = 0{,}8\, V_{e50}(z)$$

Turbulent:

$$V_{50}(z) = V_{ref}\left(z / z_{hub}\right)^{0{,}11}$$

$$V_1(z) = 0{,}8\, V_{50}(z)$$

$$\sigma_1 = 0{,}11\, V_{hub}$$

Turbulence

Mann and Kaimal Model

$$\sigma_1 = I_{\mathrm{ref}}(0{,}75V_{\mathrm{hub}} + b); \quad b = 5{,}6\ \mathrm{m/s}$$

– lateral component – $\sigma_2 \geq 0{,}7\sigma_1$

– upward component – $\sigma_3 \geq 0{,}5\sigma_1$

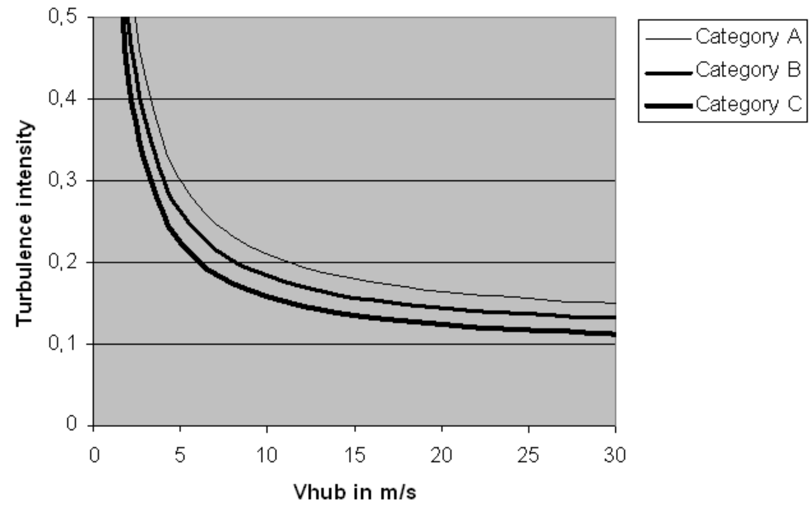
$$\Lambda_1 = \begin{cases} 0{,}7\,z & z \leq 60\,m \\ 42\,m & z \geq 60\,m \end{cases}$$

Inertial subrange

$$S_1(f) = 0{,}05\,\sigma_1^2 (\Lambda_1 / V_{\mathrm{hub}})^{-2/3} f^{-5/3}$$

$$S_2(f) = S_3(f) = \tfrac{4}{3} S_1(f)$$

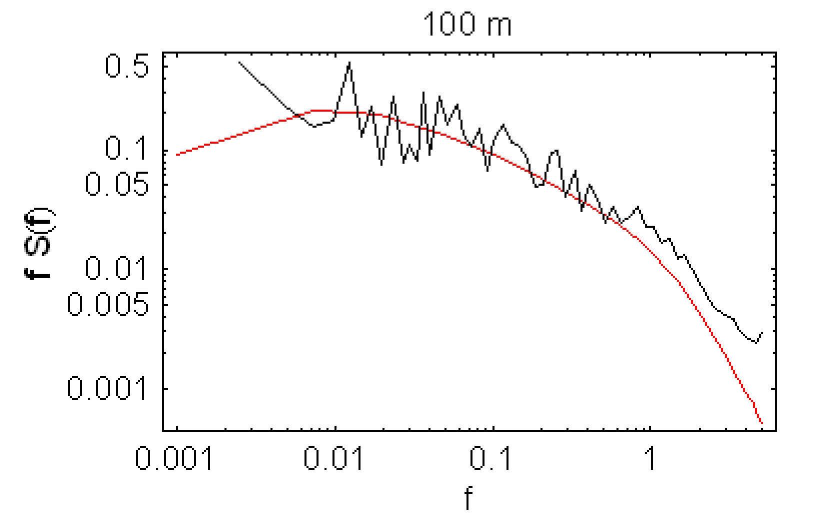
Figure 1b – Turbulence intensity for the normal turbulence model (NTM)

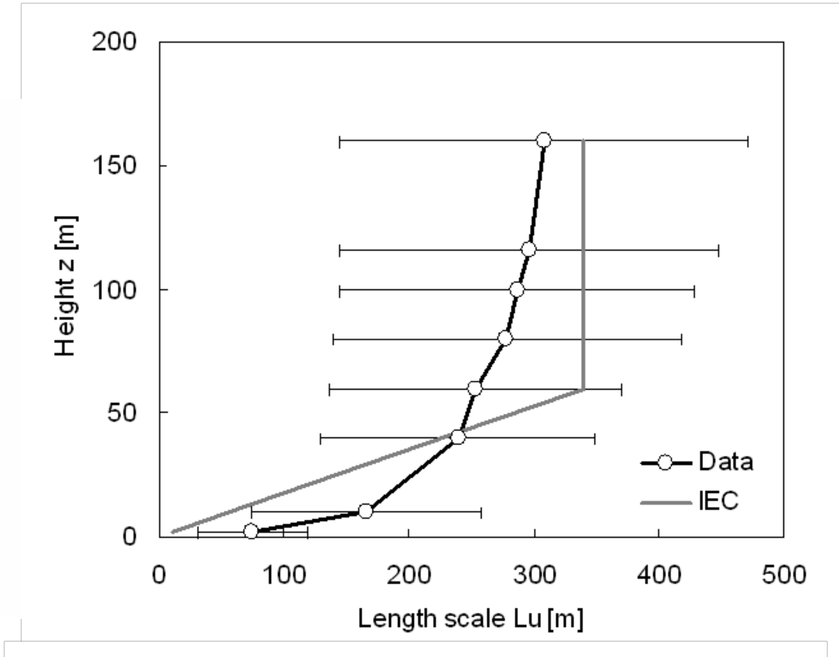


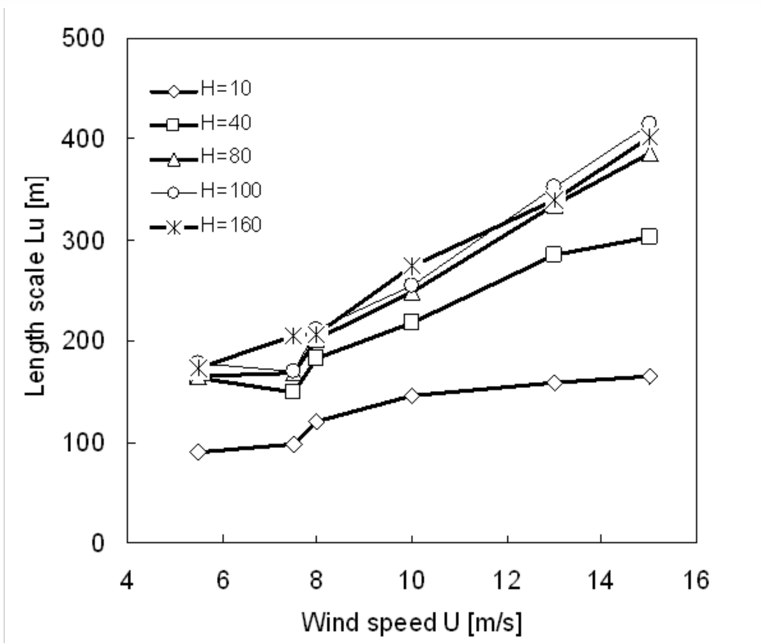
$$E\langle \sigma_1 | V_{\mathrm{hub}} \rangle = I_{\mathrm{ref}}(0{,}75V_{\mathrm{hub}} + c); \; c = 3{,}8\ \mathrm{m/s}$$

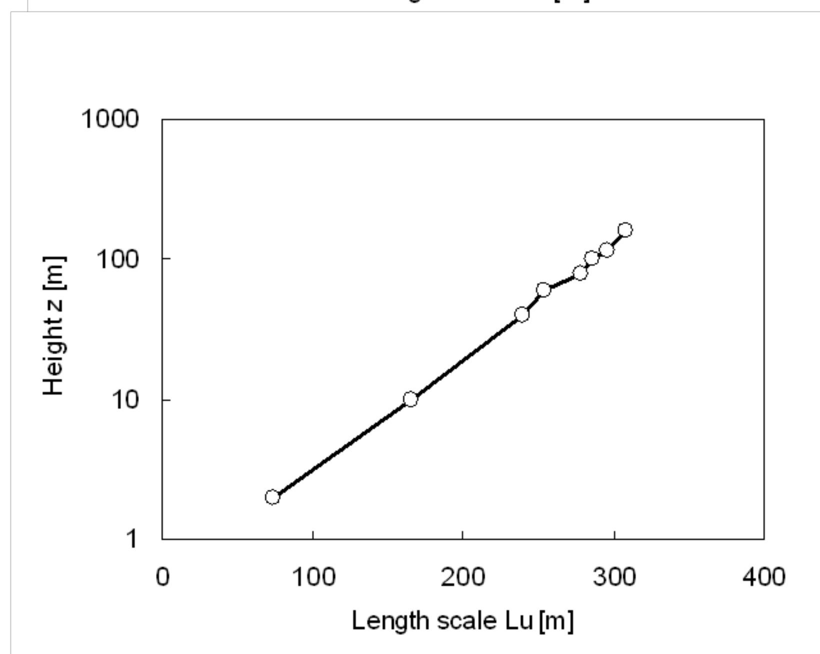
$$Var\langle \sigma_1 | V_{\mathrm{hub}} \rangle = (I_{\mathrm{ref}}(1{,}4\ \mathrm{m/s}))^2$$

Measurements









Extreme turbulence model

Based on 50-year return period and log-normal TI:

Normalized turbulence:

$$\frac{\sigma_1}{I_{ref} \times 1.44 m/s}$$

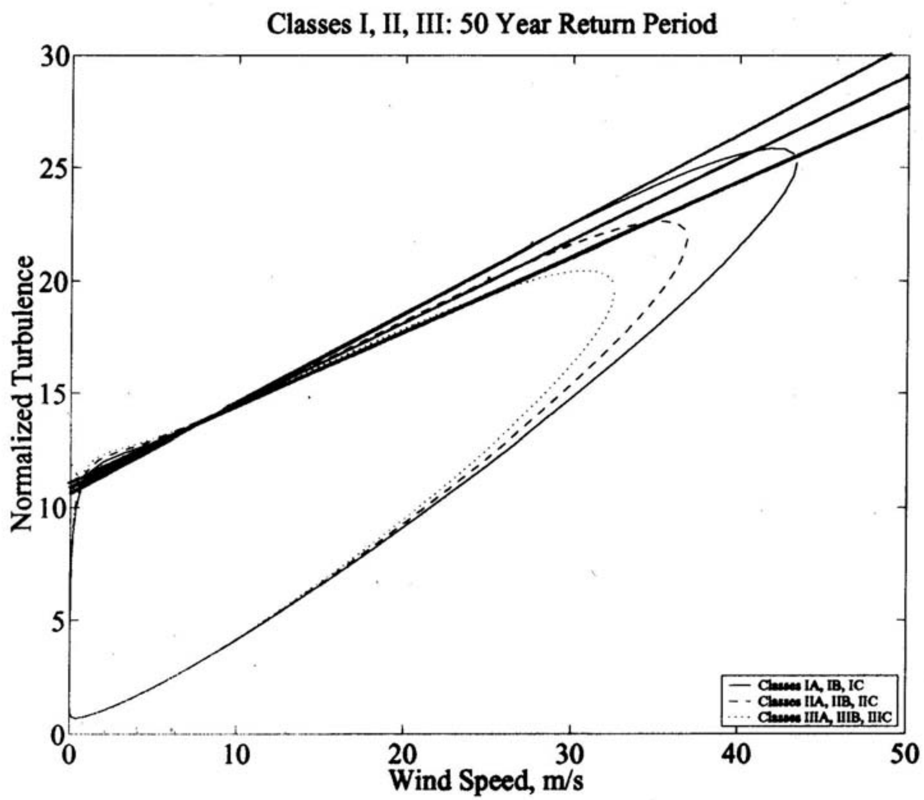
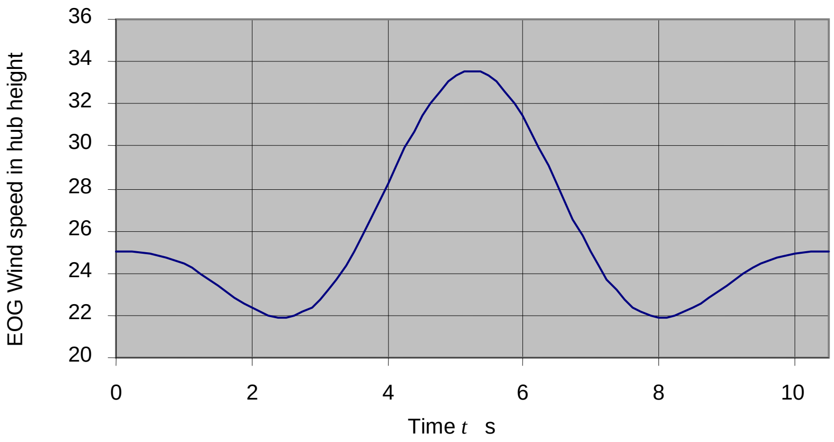


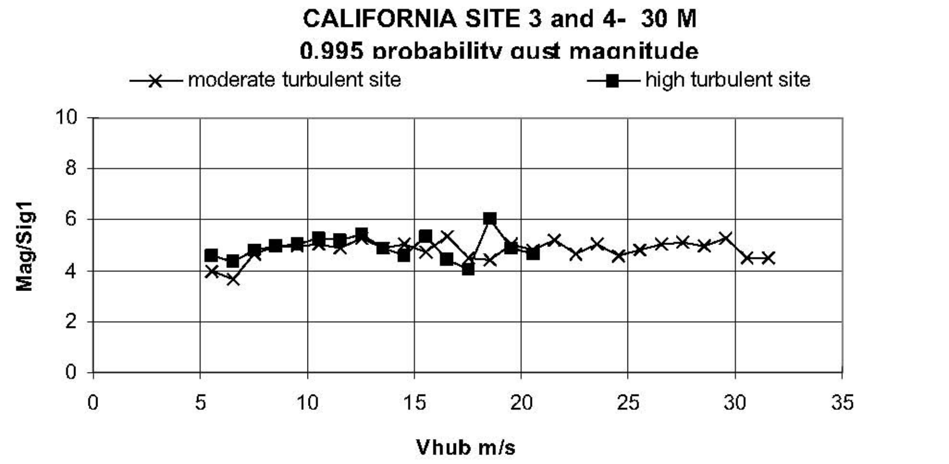
Figure 12: Environmental contour with normalized turbulence intensity, wind classes I-III,50-year return period.

$$\sigma_1 = c \quad I_{ref}\left(0{,}072\left(\frac{V_{ave}}{c}+3\right)\left(\frac{V_{hub}}{c}-4\right)+10\right); \; c = 2 \quad \text{m/s.}$$

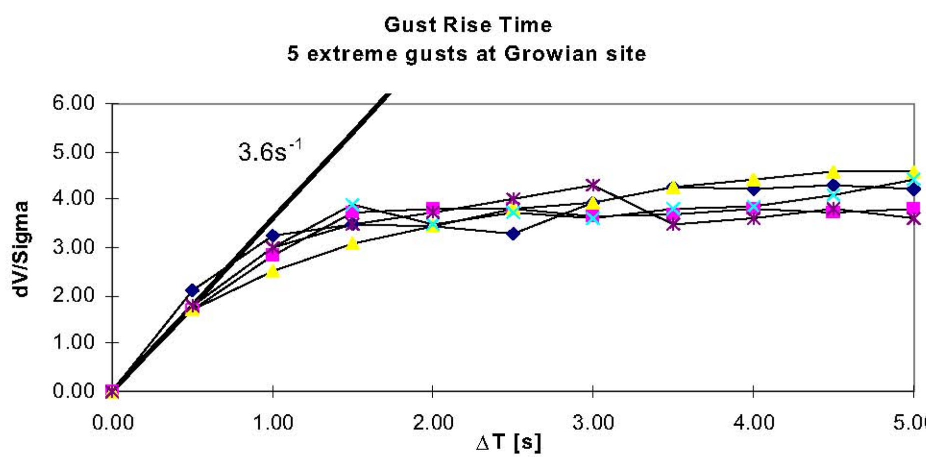
Gust models

- Extreme operating gust (EOG)





- Extreme direction change (EDC)
- Extreme coherent gust with direction change (ECD)
- Extreme wind shear (EWS)



IEC 61400-1 Design Load cases

Table 2 – Design load cases

Design situation	DLC	Wind condition		Other conditions	Type of analysis	Partial safety factors
1) Power production	1.1	NTM	$V_{in} < V_{hub} < V_{out}$	For extrapolation of extreme events	U	N
	1.2	NTM	$V_{in} < V_{hub} < V_{out}$		F	*
	1.3	ETM	$V_{in} < V_{hub} < V_{out}$		U	N
	1.4	ECD	$V_{hub} = V_r$-2 m/s, V_r, V_r+2 m/s		U	N
	1.5	EWS	$V_{in} < V_{hub} < V_{out}$		U	N
2) Power production plus occurrence of fault	2.1	NTM	$V_{in} < V_{hub} < V_{out}$	Control system fault or loss of electrical network	U	N
	2.2	NTM	$V_{in} < V_{hub} < V_{out}$	Protection system or preceding internal electrical fault	U	A
	2.3	EOG	$V_{hub} = V_r \pm 2$ m/s and V_{out}	External or internal electrical fault including loss of electrical network	U	A
	2.4	NTM	$V_{in} < V_{hub} < V_{out}$	Control, protection, or electrical system faults including loss of electrical network	F	*
3) Start up	3.1	NWP	$V_{in} < V_{hub} < V_{out}$		F	*
	3.2	EOG	$V_{hub} = V_{in}$, $V_r \pm$ 2m/s and V_{out}		U	N
	3.3	EDC	$V_{hub} = V_{in}$, $V_r \pm$ 2m/s and V_{out}		U	N
4) Normal shut down	4.1	NWP	$V_{in} < V_{hub} < V_{out}$		F	*
	4.2	EOG	$V_{hub} = V_r \pm 2$ m/s and V_{out}		U	N
5) Emergency shut down	5.1	NTM	$V_{hub} = V_r \pm 2$ m/s and V_{out}		U	N
6) Parked (standing still or idling)	6.1	EWM	50-year recurrence period		U	N
	6.2	EWM	50-year recurrence period	Loss of electrical network connection	U	A
	6.3	EWM	1-year recurrence period	Extreme yaw misalignment	U	N
	6.4	NTM	$V_{hub} < 0,7\ V_{ref}$		F	*
7) Parked and fault conditions	7.1	EWM	1-year recurrence period		U	A
8) Transport, assembly, maintenance and repair	8.1	NTM	V_{maint} to be stated by the manufacturer		U	T

Turbine operation

- normal power production
- start up and shut down
- control failure or network failure
- parked or idling state
- yaw error

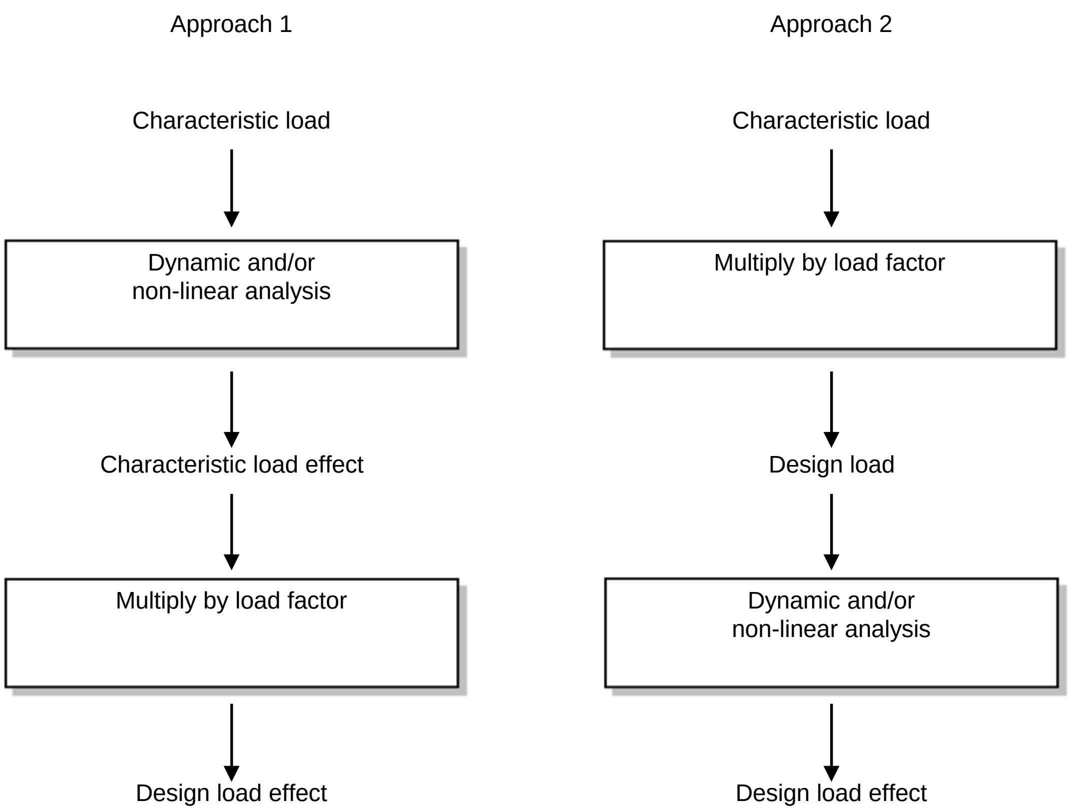
Wind conditions

- Extreme wind
- Wind distribution
- Turbulence
- Wind shear
- Dynamic events

Load type

- Fatigue loads
- Ultimate load

The design load effect



$$\gamma_f F_k \le \frac{1}{\gamma_n} \cdot \frac{1}{\gamma_m} f_k$$

Partial Safety Factors for Loads (ultimate)

Unfavourable loads			Favourable* loads
Type of design situation (see Table 2)			All design situations
Normal (N)	Abnormal (A)	Transport and erection (T)	
1,35*	1,1	1,5	0,9

* For design load case DLC 1.1, given that loads are determined using statistical load extrapolation at prescribed wind speeds between V_{in} and V_{out}, the partial load factor for normal design situations shall be γ_f =1,25.

If for normal design situations the characteristic value of the load response $F_{gravity}$ due to gravity can be calculated for the design situation in question, and gravity is an unfavourable load, the partial load factor for combined loading from gravity and other sources may have the value

$$\gamma_f = 1{,}1 + \varphi \varsigma^2$$

$$\varphi = \begin{cases} 0{,}15 & \text{for DLC1.1} \\ 0{,}25 & \text{otherwise} \end{cases}$$

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

* Pretension and gravity loads that significantly relieve the total load response are considered favourable loads. In the case of both favourable and unfavourable loads, the limit state function becomes

$$\gamma_n S\left(\gamma_{f,unfav} F_{k,unfav}, \gamma_{f,fav} F_{k,fav}\right) \le R(f_d)$$

Partial Safety Factors (ultimate)

Partial safety factors for consequences of failure:

- Component class 1: γ_n = 0,9
- Component class 2: γ_n = 1,0
- Component class 3: γ_n = 1,3

General partial safety factor for materials, γ_m:

$$\gamma_m \geq 1{,}1$$

applied to characteristic material properties of 95 % survival probability, *p*, with 95 % confidence limit

For "non fail-safe" mechanical /structural components with non-ductile behaviour γ_m shall be not less than:

- 1,2 for global buckling of curved shells such as tubular towers and blades, and
- 1,3 for rupture from exceeding tensile or compression strength.

MINIMUM REQUIREMENTS !!

Partial Safety Factors (fatigue)

Miner's rule

For loads and all normal and abnormal design situations

$\gamma_f = 1,0$

Partial safety factors for consequences of failure:

- Component class 1: $\gamma_n = 1,0$
- Component class 2: $\gamma_n = 1,15$
- Component class 3: $\gamma_n = 1,3$.

MINIMUM REQUIREMENTS !!

For materials:

$\gamma_m \geq 1,5$

provided that the SN curve is based on 50 % survival probability and COV<15 %.

Welded and structural steel:

$\gamma_m = 1,1$

with the 97,7 % survival probability is used as basis for the SN curves.

Fibre composites:

$\gamma_m = 1,2$

with 95 % survival probability with a confidence level of 95 % shall be used as a basis for the SN-curve

Assessment of a wind turbine for site-specific conditions

Two approaches:

- a demonstration that all these conditions are no more severe than those assumed for the design of the wind turbine;
- a demonstration of the structural integrity for conditions, each equal to or more severe than those at the site.

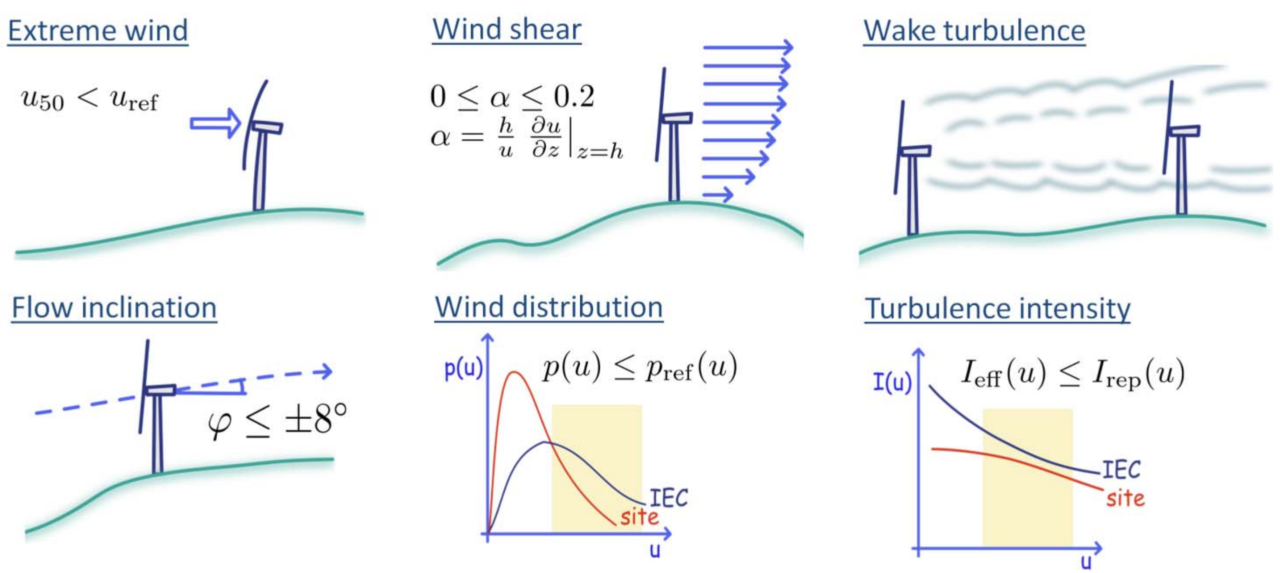
Site conditions:

- Topographical complexity;
- Wind conditions;
- Air density;
- Earthquake;
- Electrical network conditions;
- Soil conditions.

IEC 61400-1 site assessment rules

Checklist

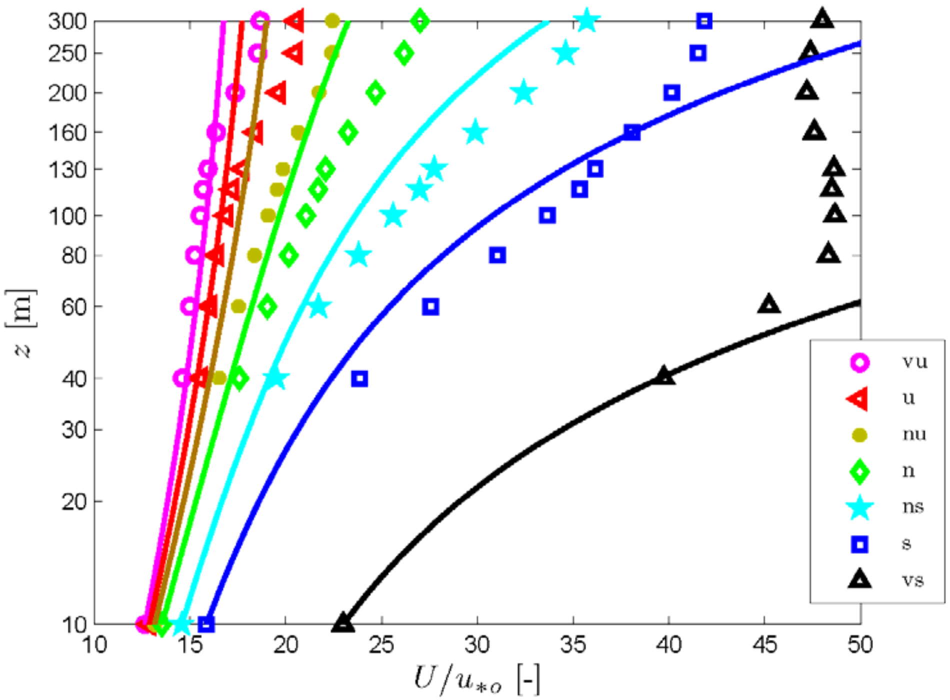
- Extreme winds
- Shear of vertical wind profile
- Flow inclination
- Background turbulence
- Wake turbulence
- Wind-speed distribution

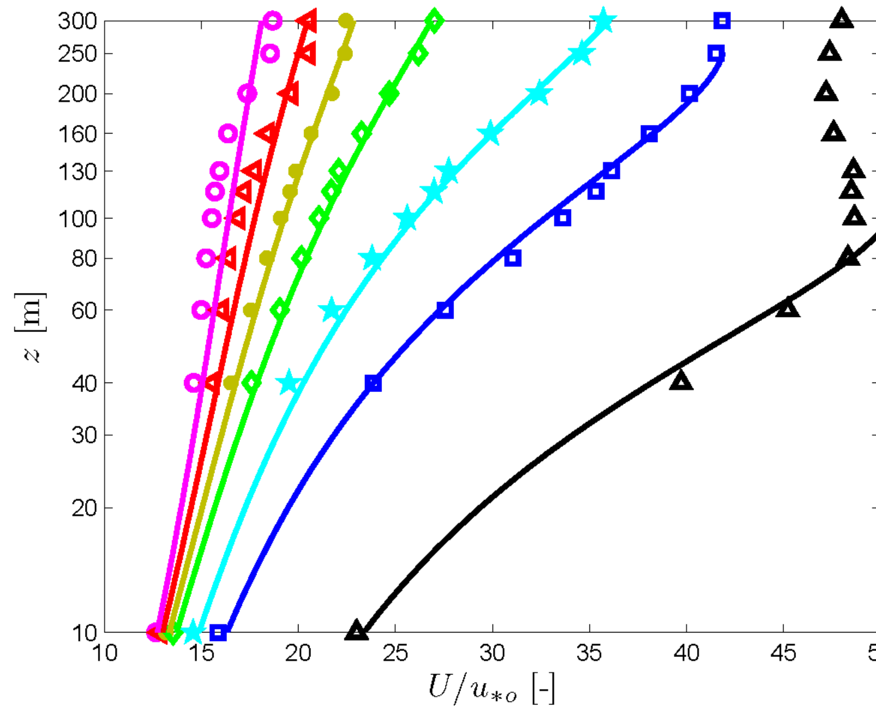


12MW project 2006-2009
Høvsøre cup/lidar to 300 m

Lines show logarithmic wind profile.
Symbols show data.
Notice good correspondance only at <40 m height.

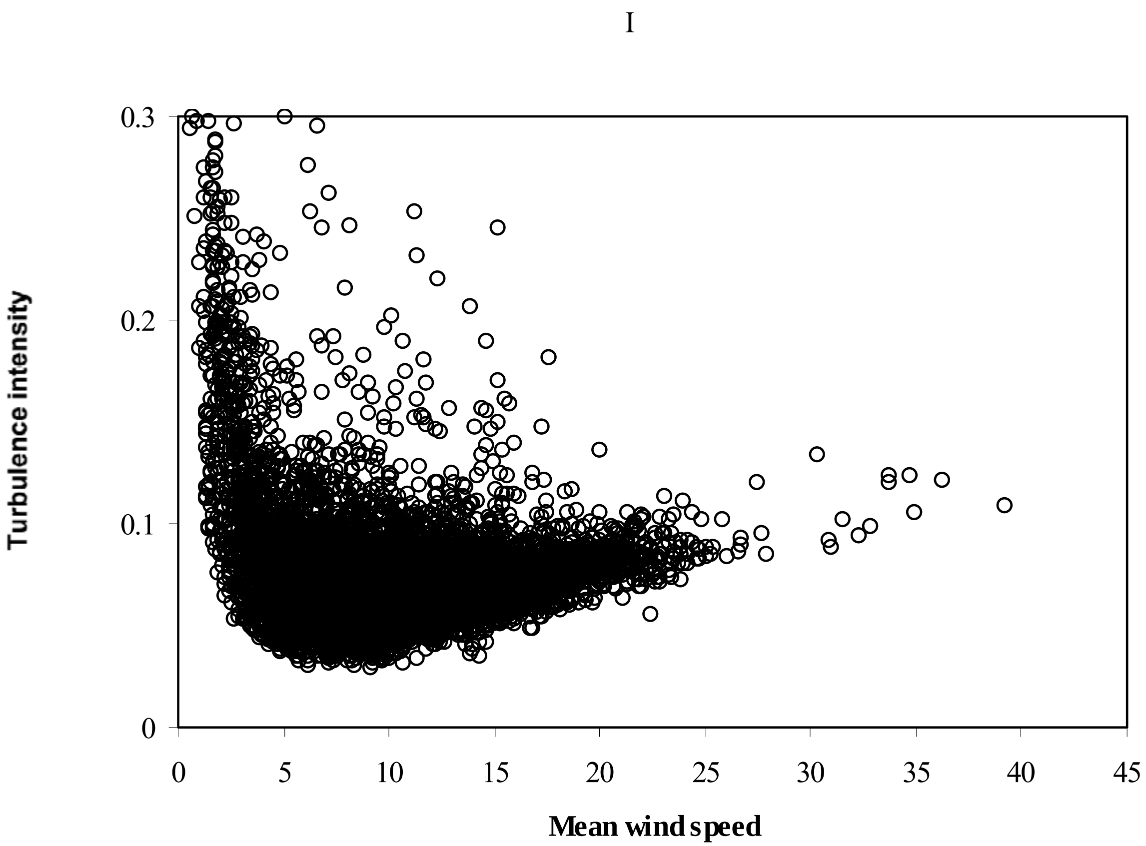
Lines show mixing-length profile *using boundary layer height.*
Symbols show data.
Notice good correspondance at all heights in the boundary layer.





Colours: atmospheric stability - vu very unstable, n neutral, vs very stab

Measured turbulence intensity

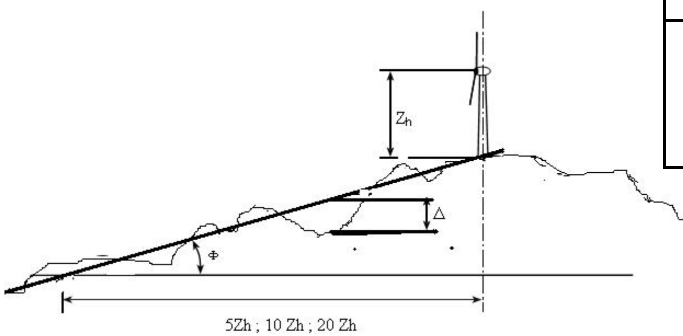


Turbulence intensity measurements at Horns Rev, h=62m, No. of 10min values 7500.

Assessment of the topographical complexity of a site

- 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

Distance range from wind turbine	Sector amplitude	Max slope of fitted plane	Maximum terrain variation
< 5 zhub	360º		< 0,3 zhub
< 10 zhub	30º	< 10 º	< 0,6 zhub
< 20 zhub	30º		< 1,2 zhub



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

C_{CT} = 1+0,15 i_c

The resolution of surface grids must not exceed the smallest of 1.5 *zhub* and 100 m. 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.

Thank you for your attention

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