IEC61400-1 ed. 3
Load Cases, Extremes and Fatigue loads

Risø DTU
National Laboratory for Sustainable Energy

Principles

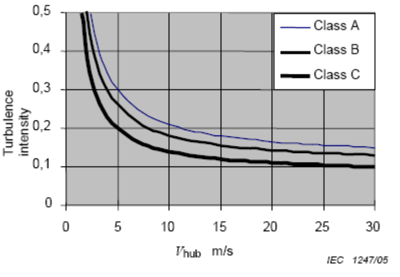
- “specifies essential **design requirements** to ensure the engineering integrity of wind turbines. Its purpose is to provide an appropriate level of protection against damage from all hazards during the planned lifetime”
- “requires the use of a **structural dynamics model** to predict design loads. Such a model shall be used to determine the loads over a range of wind speeds, using the turbulence conditions and other wind conditions defined in…”
- not offshore (then IEC61400-3)
- turbines of all sizes

Turbine classes

- Classification standard

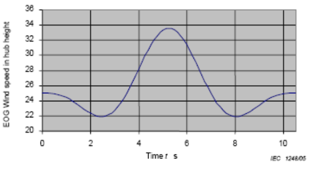
Table 1 – Basic parameters for wind turbine classes[1]

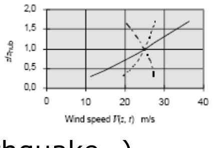
Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values specified by the designer
A	I_{ref} (-)	0,16			
B	I_{ref} (-)	0,14			
C	I_{ref} (-)	0,12			

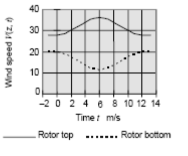


Environmental conditions

- Normal wind conditions
  - Distribution
  - Profile
  - Turbulence model
- Extreme wind conditions
  - Extreme wind speed
  - Extreme operating gust
  - Extreme turbulence model
  - Extreme direction change
  - Gust and direction change
  - Extreme wind shear
- Other conditions (e.g. earthquake…)







Load cases 1

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	*

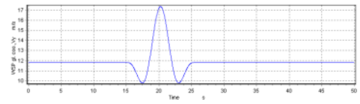
"At least six 10-min stocastic realizations (or a continuous 60min period) shall be required for each mean, hub-height wind speed used in the simulations. However for DLC 2.1,2.2,5.1 at least 12 simulations shall be carried out for each event at the given wind speed."

Load cases 2

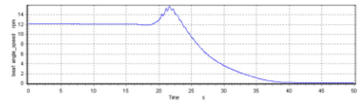
3) Start up	3.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	3.2	EOG $V_{hub} = V_{in}$, $V_r \pm 2$ m/s and V_{out}		U	N
	3.3	EDC $V_{hub} = V_{in}$, $V_r \pm 2$ m/s and V_{out}		U	N
4) Normal shut down	4.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	4.2	EOG $V_{hub} = V_r \pm 2$ m/s and V_{out}		U	N
5) Emergency 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
	8.2	EWM 1-year recurrence period		U	A

Sample load case: EOG with electrical generator fault

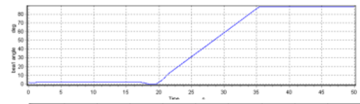
```
begin wind ;
  density                 1.225 ;
  wsp                     14  ;
  tint                  0 ;
  horizontal_input        1     ;           0=false, 1=true
  windfield_rotations     0  0.0  0.0 ;    yaw, tilt, rotation
  center_pos0             0.0 0.0 -90.0 ;
  shear_format            3  0.2 ;
  turb_format             0     ;  0=none, 1=mann,2=flex
  tower_shadow_method     1     ;  0=none, 1=potential flow
;  scale_time_start        0 ;
  wind_ramp_factor   0.0 50 0.57 1.0 ;
;
  iec_gust eog 6.248088  0 100  10.5 ;
;
begin tower_shadow_potential;
    tower_offset 0.0 ;
    nsec  2;
    radius      0.0   4.0 ;
    radius    -90.0   1.94 ;
  end tower_shadow_potential;
end wind;
```



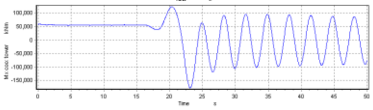
Wind:



Rot. speed:



Pitch:



Tower bot.

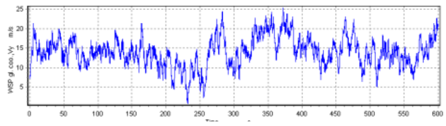
Tilt moment:

iec_gust eog 6.248088 0 100 10.5 ; Type, Vgust, Theta (not used here), t0, T

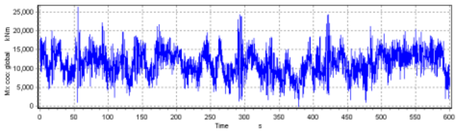
$$V(z,t) = \begin{cases} V(z) - 0{,}37\,V_{\text{gust}} \sin(3\pi t/T)\left(1-\cos(2\pi t/T)\right) & \text{for } 0 \le t \le T \\ V(z) & \text{otherwise} \end{cases}$$

$$V_{\text{gust}} = \text{Min}\left\{ 1{,}35\,(V_{e1} - V_{\text{hub}});\; 3{,}3\left(\frac{\sigma_1}{1+0{,}1\left(\frac{D}{\Lambda_1}\right)}\right)\right\}$$

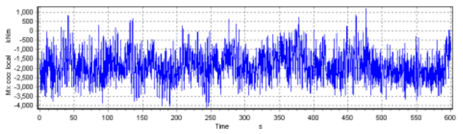
Sample load case: 14 m/s ETM (27%)



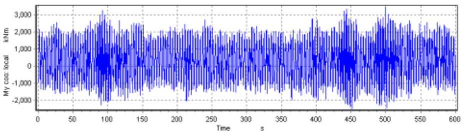
Wind



Tower long. bending



Flap



Edge

Analysis of load response time series

- Ultimate load analysis – can the components withstand the largest loads ?
- Fatigue load analysis – can the components withstand the combination of all loads ?
- (Functional requirements, deflections, ...)