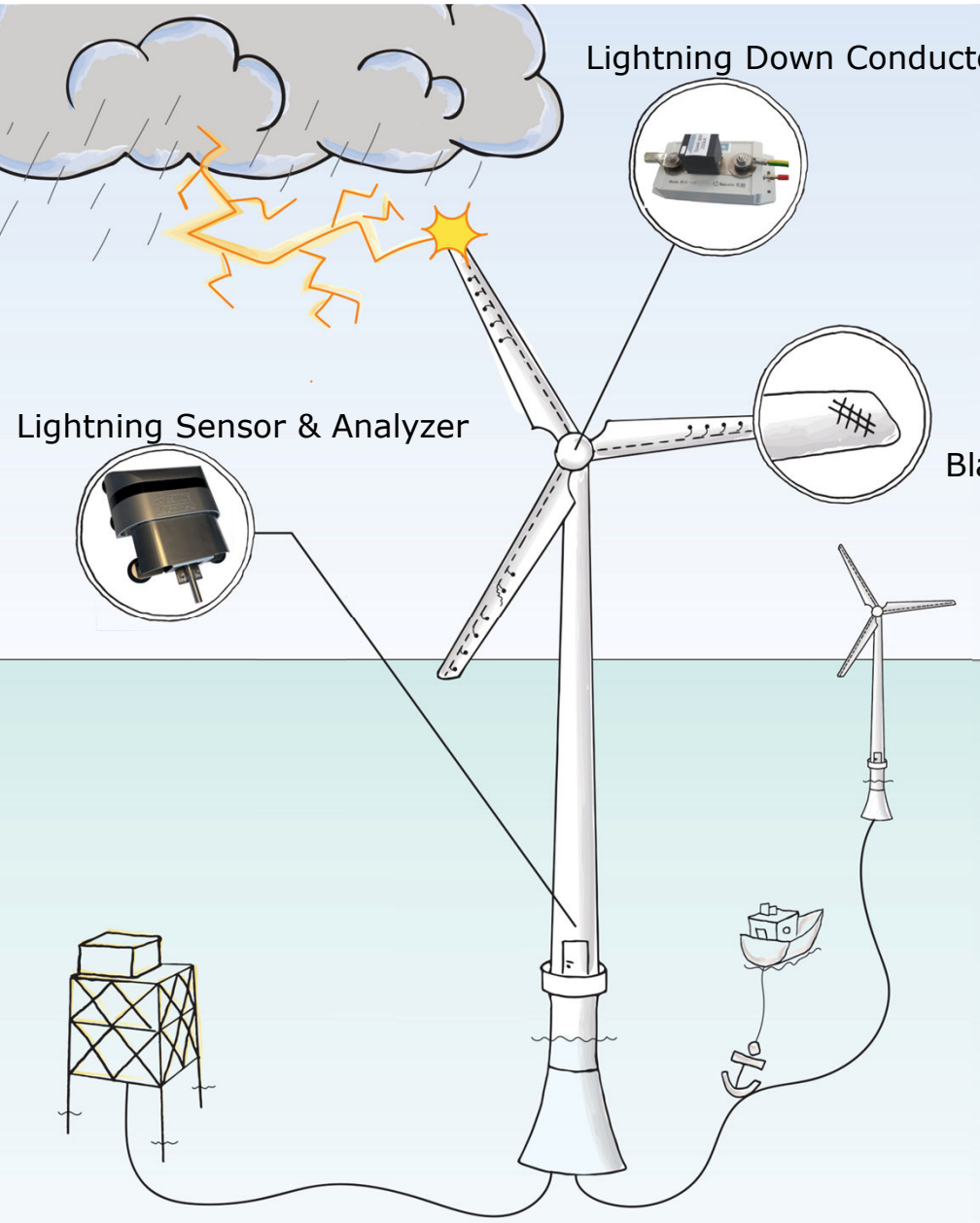

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Partnering with EOLOGIX-PING

November 2025

Are lightning standards useful ?

Standards used when designing wind turbines

IEC 61400-24 / JIS C 1400-24 / JEM-1515
Wind Energy Generating Systems, Lightning Protection

IEC62561-3
Lightning Protection system components, Requirements for isolating spark gaps

IEC62305-1
Protection against lightning

.. and related standards

The standards promote good design practices and advise how to test individual components.

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Why do we use standards ?

We want a common reference for the technical requirements to build reliable turbines and to operate these in a reliable manner to protect the investments

Do the standards fulfill the intent ?

If yes; The turbines should primarily fail in force majeure situations, i.e. where the limits of the standards are exceeded

As such, service needs should be very limited.

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A brief history of the foundation for lightning standards

The evolution of lightning standards

In the 1970s, researchers made a number of measurements of lightning strikes at high radio and TV towers in Switzerland, Canada and Brazil.

Using oscilloscopes and sensor technology of the time, they captured lightning waveforms, and used these for statistical classification.

Potential biases, in a broader context, include geographical, sensor, as well as the structural properties of the towers measured.

Resulting standards

- The statistical classification lead to the definition of Lightning Protection Levels, grouped I-IV
- The many measures included in each group, was never correlated with lightning damage risk

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IEC61400-24 LPL lightning parameters

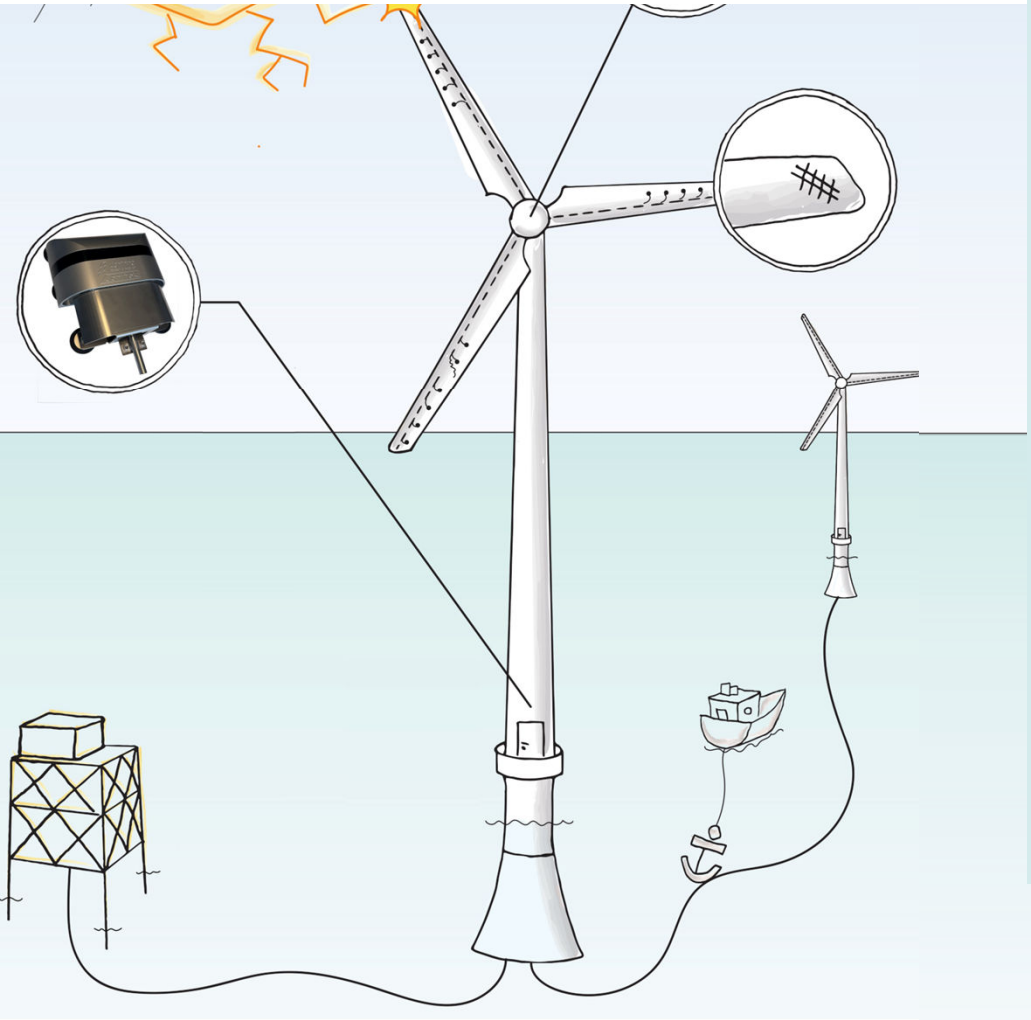

Table 1 – Maximum values of lightning parameters according to LPL (adapted from IEC 62305-1)

Current parameters		Symbol	Unit	LPL			
				I	II	III	IV
First positive short stroke	Peak current	I	kA	200	150	100	
	Charge	Q_{SHORT}	C	100	75	50	
	Specific energy	W/R	MJ / Ω	10	5,6	2,5	
	Time parameters	T_1 / T_2	µs / µs	10/350			
First negative short stroke [a]	Peak current	I	kA	100	75	50	
	Average steepness	di/dt	kA / µs	100	75	50	
	Time parameters	T_1 / T_2	µs / µs	1/200			
Subsequent short stroke	Peak current	I	kA	50	37,5	25	
	Average steepness	di/dt	kA / µs	200	150	100	
	Time parameters	T_1 / T_2	µs / µs	0,25 / 100			
Long stroke	Charge	Q_{LONG}	C	200	150	100	
	Time parameter	T_{LONG}	s	0,5			
Flash	Charge	Q_{FLASH}	C	300	225	150	

[a] First negative stroke concerns only calculations and not testing.

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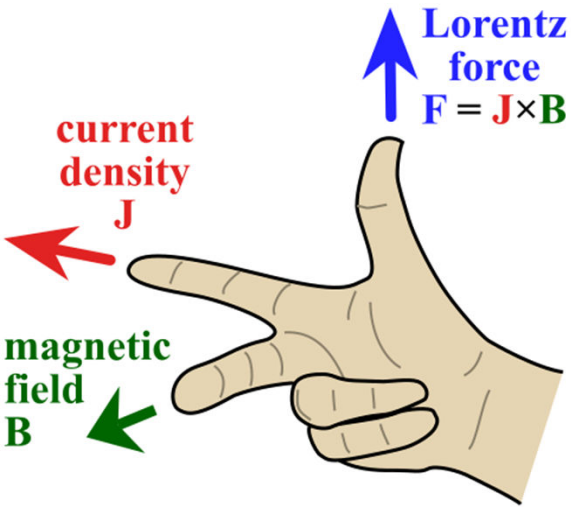

Key electrical parameters, according to LPL definitions

(1) Peak current [A]

(2) Specific energy [J/Ω]

(3) Average steepness [A/s]

(4) Charge [C]

What do they tell ?

Damage correlation

(1) Magnetic Lorentz force: **F** = **J** · **B**, where **J** scales with the current

(2) Resistive heating: Flash melting or evaporation of materials

(3) Induced emf (energy): Ɛ = dφ/dt, where φ scales with the steepness

(4) ?

New to 61400-24

Annex L (informative)
”It is recommended to measure lightning strikes”

Annex L define different classes of lightning sensors (1-4)

Damage results without preventive actions

So you may meet 61400-24 requirements, but without knowing:

- How lightning affects the turbine as an integrated whole
- If the LPL levels truly apply to the properties of the turbine structure and the geographical region
- If damages are due to strikes within or outside relevant LPLs

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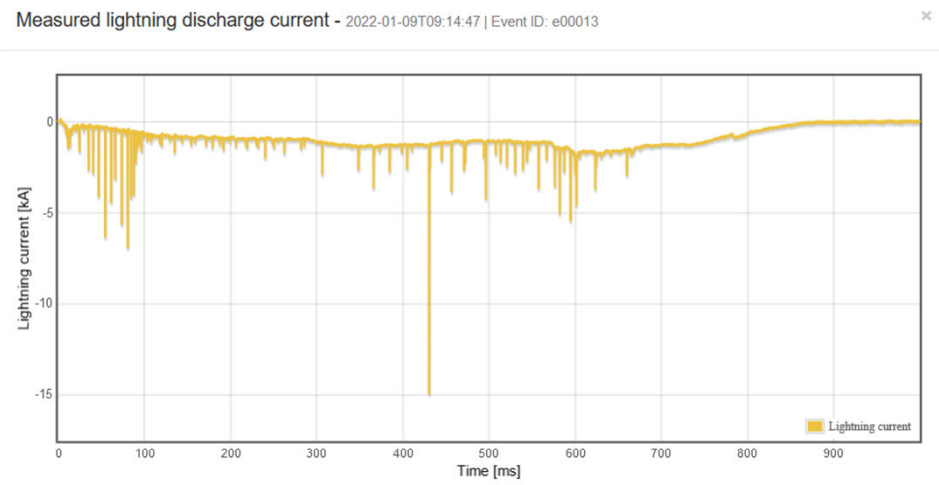
Real-world lightning case examples

Low current lightning. Breaking LPL I, but no damage.



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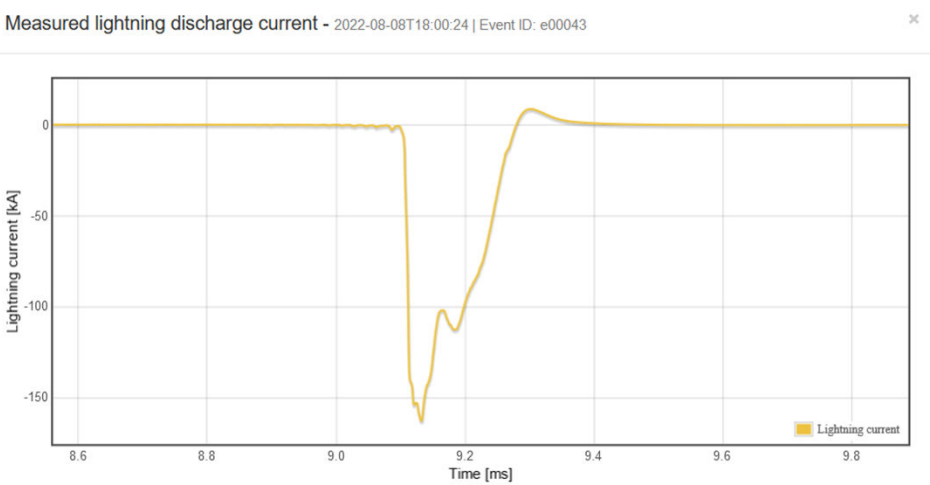
LPL I parameters	Measurement	LPL I limit
Peak current	-14.88kA	*±200kA*
Specific energy	20.99kJ/Ω	*10MJ/Ω*
Maximum peak current	-6.91kA	*±50kA*
Average steepness	-2.1kA/µs	*±200kA/µs*
Charge, flash	889.98C	*300 / 600C*
Charge, long	110.96C	*200C*
Charge, short	4.11C	*100C*

Additional parameters	Measurement	Service limit
Polarity of main stroke	Negative	-
Total specific energy	1098.43kJ/Ω	*5000kJ/Ω*
Receptor mass loss	0.02g	-
Inductive energy index	∝0.7J	*∝5J*
Pulse count	16	-
Shortest rise time	3.48µs	-
LPL I severity	296.7	*100.0*

High peak current lightning. Below LPL I, blade destroyed.



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LPL I parameters	Measurement	LPL I limit
Peak current	-162.24kA	*±200kA*
Specific energy	1721.96kJ/Ω	*10MJ/Ω*
Maximum peak current	0.0kA	*±50kA*
Average steepness	-10.68kA/µs	*±200kA/µs*
Charge, flash	23.41C	*300 / 600C*
Charge, long	0.0C	*200C*
Charge, short	15.32C	*100C*

Additional parameters	Measurement	Service limit
Polarity of main stroke	Negative	-
Total specific energy	1727.39kJ/Ω	*5000kJ/Ω*
Receptor mass loss	0.03g	-
Inductive energy index	∝27.58J	*∝5J*
Pulse count	1	-
Shortest rise time	15.19µs	-
LPL I severity	81.1	*100.0*

Additional real-world examples can be found via http://jomitek.dk/lsa.php

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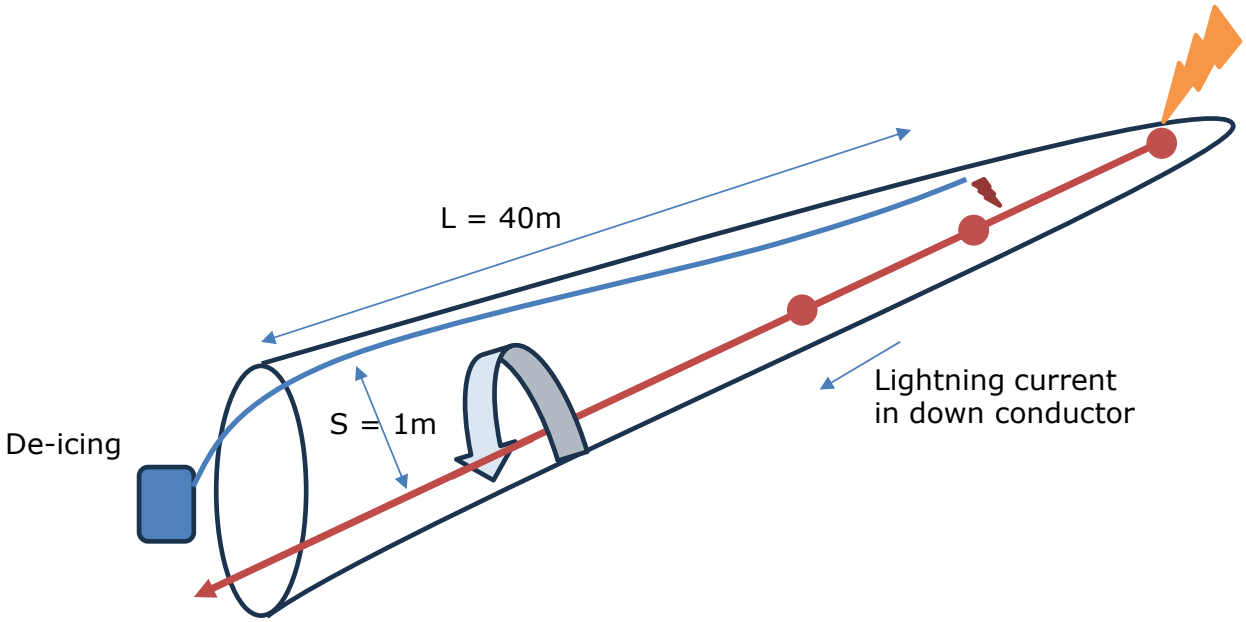
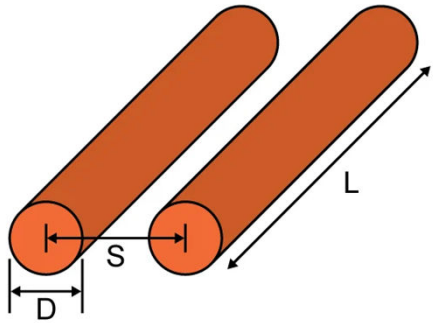
Example risk factor, challenging to address in practice: Electrical arching (1/2)



$$L_{wires} \approx \frac{\mu_o \mu_r L}{\pi} \cosh^{-1}\left(\frac{S}{D}\right)$$



L=40m
D=0,01m
S=1m

Induced voltage between parallel wires: $U = L_{wires} \cdot dI/dt$

Assuming dI/dt = **10kA/µs**, the example blade geometry risk induced voltages >800kV in the parallel wire

The real physics of the example is complex. The example illustrates the **risk of electrical arching in the blade** due to induced voltage

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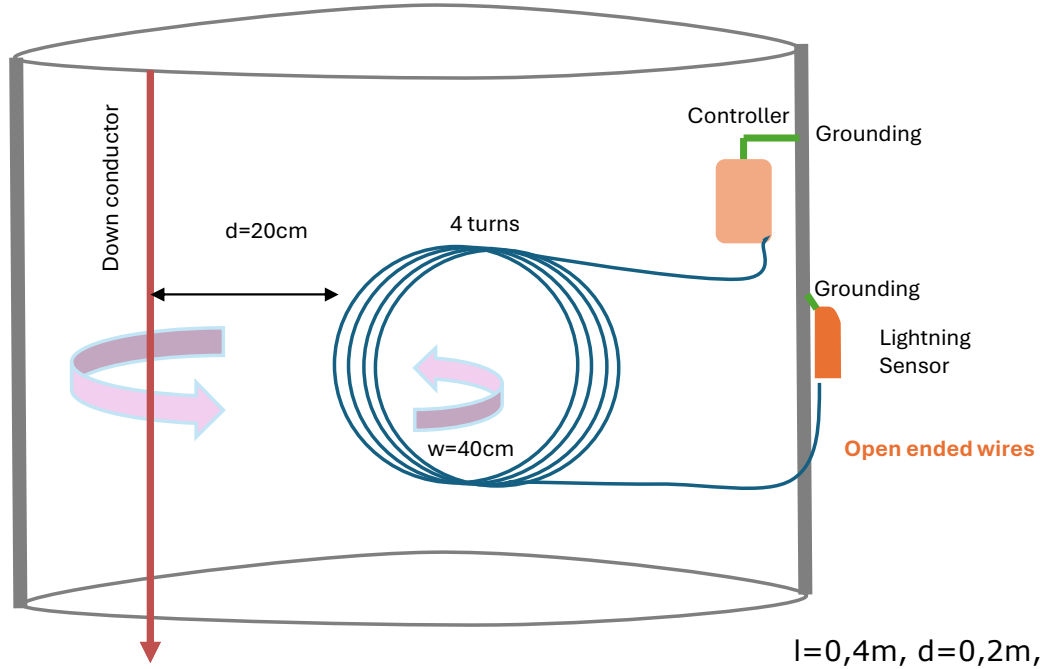
Example risk factor, challenging to address in practice: Induced voltage (2/2)



l=0,4m, d=0,2m, w=0,4m, 4 turns

Induced voltage in signal wire: $U \approx \mu_0 / 2\pi \cdot l \cdot \ln((d+w)/d) \cdot dI/dt$

Assuming dI/dt = **10kA/µs**, the example coil geometry risk induced voltages >3kV across open ended wires.

Many electrical components will degrade or become non-functional at such levels.

Lightning pulse magnetically induced voltages, and associated energy, **can not be protected against** with high EMC ratings incl. shielding

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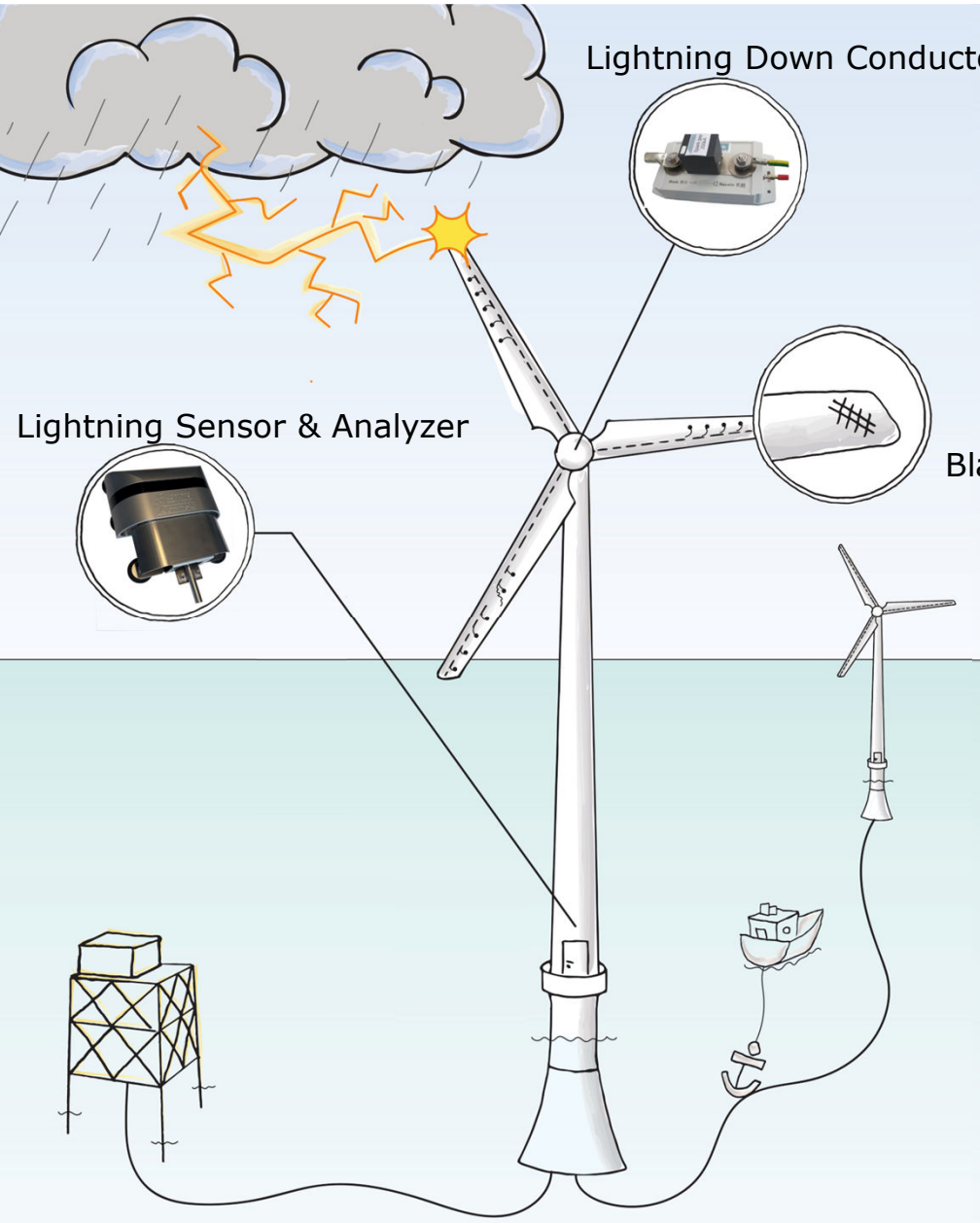

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Are lightning standards useful ?

They currently link poorly to the underlying damage risk and do not promote iterative design improvements

- Lack correlation between parameters and associated damage
- Largely ignore the importance of induced voltages
- No requirements for measurements, just recommendation