Staying Grounded

Assessing and Mitigating Lightning Risk at Your Site

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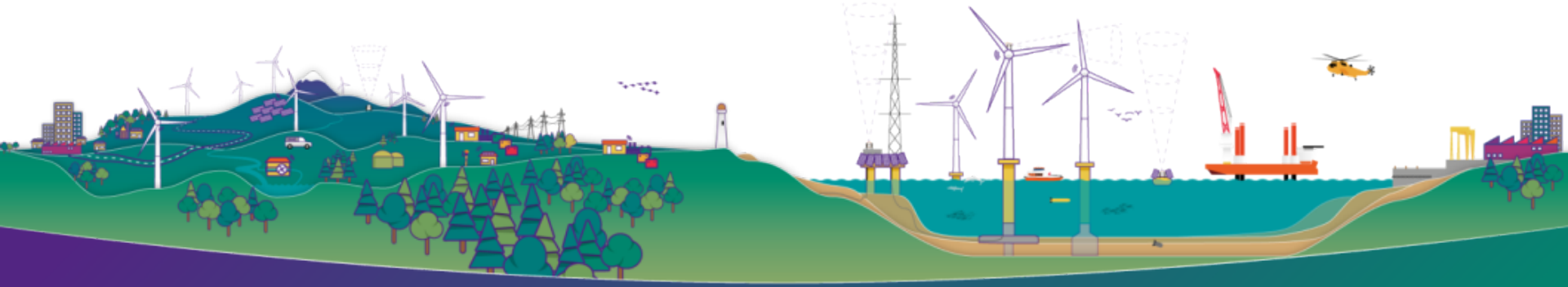

A Lightning Refresher

- What causes lightning?
  - Lightning is an electrical discharge caused by charge imbalances between storm clouds and the ground, or within the clouds themselves.


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- What characteristics of lightning should we be concerned about?
  - Polarity – lightning strikes can have a negative or positive charge
  - Amperage – magnitude of lightning strike defined by the electrical current.
  - Steepness - The rate of change of current over time.
  - Continuing Current – Is a type of lightning strike in which the current can flow for much longer than in a typical lightning discharge.

- What characteristics of blade damage should we be concerned about?
  - Damage can range from minor discoloration to catastrophic failure.
  - Location of damage
  - Depth, width, and length
  - Severity of damage is rated from Category 1 to Category 5.
  - Other damage can include drive train damage, nacelle electrical arcing, and damage to electrical equipment

IEC Lightning Protection Level

Can I skip to the end of the presentation if my turbines are type certified to Lightning Protection Level 1 ("LPL 1")?

- ➜ No
- ➜ Although LPL 1 (as defined by IEC 61400-24) is the highest level of protection, it does not address lightning outside of the specified parameters nor is it intended to provide 100% protection from lightning strikes within the 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.

Lightning Risk Analysis

What are stakeholders currently doing to evaluate risk due to lightning damage?

- Turbine OEMs – currently do not include lightning risk assessment as a standard part of site suitability review.
- Project Sponsors – provide historical lightning damage reporting for a repower project. Provides high level lightning information for a project site based on operational experience in the area and with the turbine OEM.
- Independent Engineer ("IE") – provides high level risk assessment based on county level lightning maps. Can provide site-specific analysis upon request.

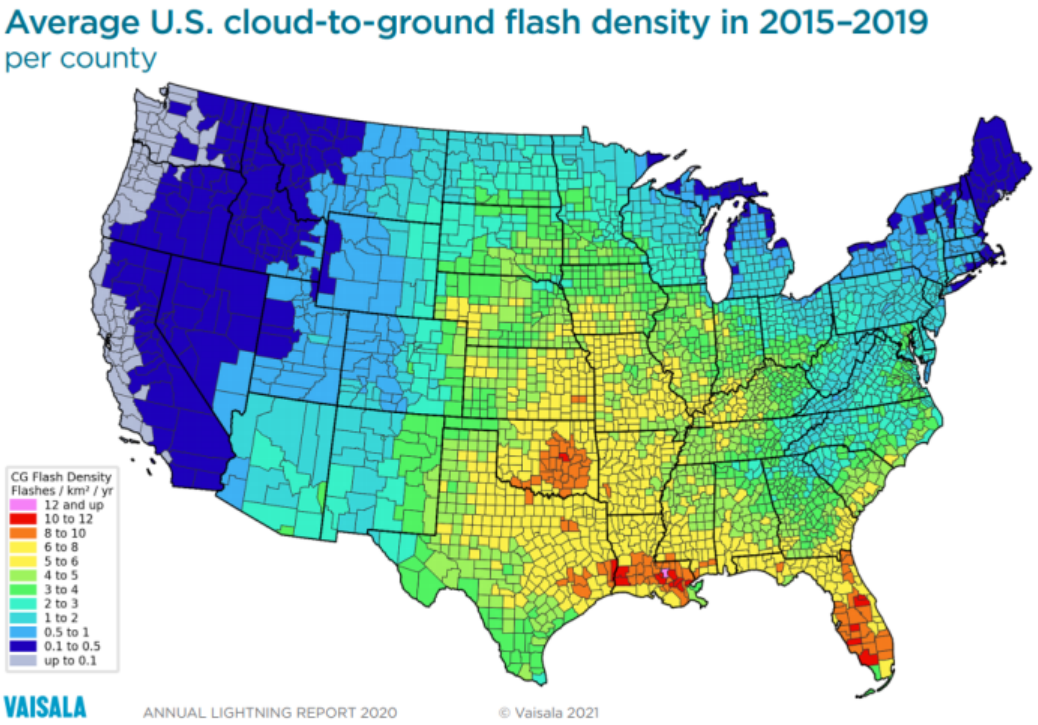
IEC 61400-24 Site-Specific Analysis

- Provides guidelines for calculating expected damage rates
- Estimate annual flashes at the wind turbine based on strike density
- Based on "collection area" which is proportional to tip height
- Incorporates some terrain characteristics such as elevation, terrain complexity, and winter lightning

Natural Power Site-Specific Analysis

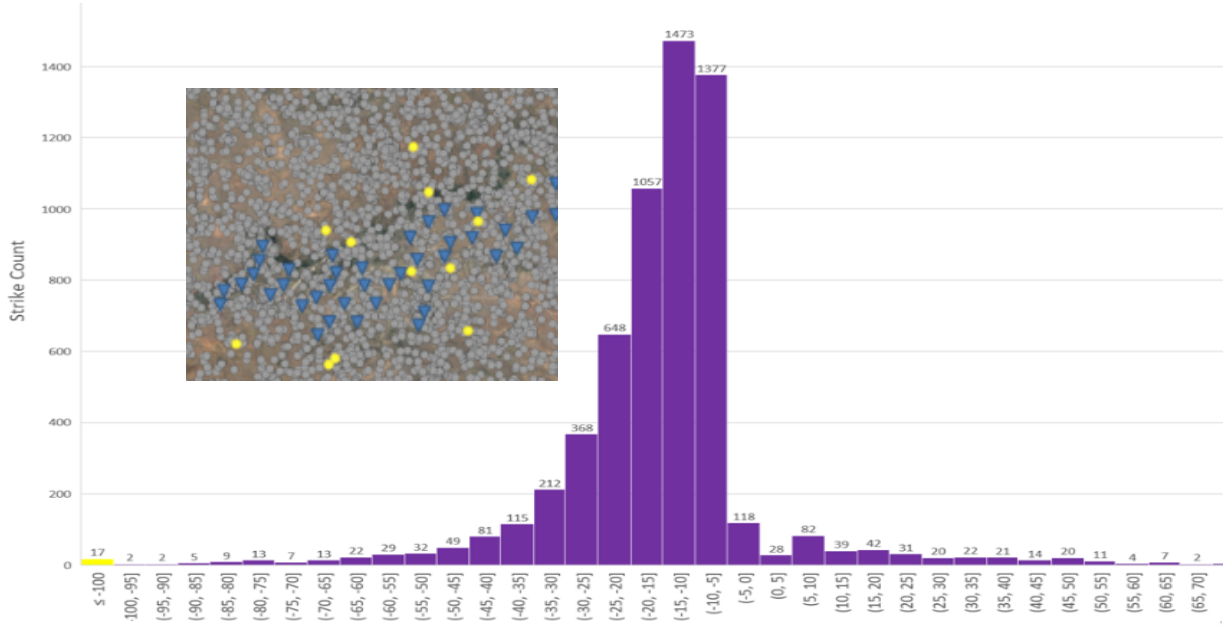
- Uses five years of historic lightning data
- Provides seasonal and annual analysis
- Provides analysis of lightning events which exceed LPL 1 thresholds
- Expanded to 10 years of data including continuing current based on initial risk review
- Provides estimated inspection workload based on recommend inspection criteria.

Regional Results Example



Parameter	North West	South West	Midwest	Texas	North East
5-Year and 10-Year Statistics					
Total strikes (count)	25	1079	865	1723	189
Total strikes outside IEC current limits (count)	0	2	5	5	0
Total strikes outside IEC current limits (percent of total)	0.00%	0.19%	0.58%	0.29%	0.00%
Total strikes outside IEC steepness limit (count)	0	0	0	0	0
Continuing current strikes - 2020 only (count)	0	unknown	3	14	unknown
Annual Statistics					
Annual average strikes (count)	3	216	87	172	38
Annual avg. strikes outside IEC current limits (count)	0	<1	<1	<1	0
Annual avg. strikes outside IEC current limits (percent of	0.00%	0.19%	0.58%	0.29%	0.00%
Annual strikes outside IEC steepness limit (count)	0	0	0	0	0
Annual strikes outside IEC long stroke time parameter	0	unknown	0	0	unknown

Project Results Example



Jan 2016 - Dec 2020 Monthly Lightning Strikes													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2016	0	4	0	0	1	151	387	225	93	9	32	45	947
2017	7	0	0	8	43	216	210	544	261	685	0	0	1974
2018	0	0	0	0	59	64	114	603	104	14	0	0	958
2019	0	0	18	15	17	114	112	284	487	6	0	0	1053
2020	0	0	1	0	1	80	690	308	3	0	0	0	1083
Total	7	4	19	23	121	625	1513	1964	948	714	32	45	6015

Jan 2016 - Dec 2020 Monthly Strikes Requiring Inspection													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2016	0	0	0	0	0	54	102	60	34	4	13	3	270
2017	5	0	0	1	9	103	80	174	70	218	0	0	660
2018	0	0	0	0	37	15	32	181	40	1	0	0	306
2019	0	0	3	6	4	24	37	72	115	0	0	0	261
2020	0	0	0	0	0	24	190	118	0	0	0	0	332
Total	5	0	3	7	50	220	441	605	259	223	13	3	1829

Tax Equity Perspective – Historical Lightning Risk

- In the past 18-24 months we have seen multiple sites (across multiple OEMs) experiencing atypical/severe damage from lightning requiring blade replacements or lightning protection system retrofits. Some sites have had significant impacts on availability while others have pervasive damage requiring some turbines to be offline for continual repairs.

- Lack of a robust approach to translate historical/IEC analysis through to availability assumptions, operating expense projections, downside scenarios. OEM Site Suitability analysis does not address lightning risk.

- In response to these experiences Wells Fargo has dug deeper into lightning risk and, working with Natural Power, have established a set of best practices to analyze and mitigate lightning risk in our tax equity deals
  - Historical/IEC Lightning Assessment
  - Turbine Technology
  - Contracts (Turbine Supply/O&M Agreements)
  - Lightning Inspection Protocol
  - Insurance

- Owner/operators that have had a negative experience are more likely to be ahead of the curve on topics such as inspection protocols, contract negotiations, warranty claims, etc.

Risk Mitigation – Lightning Inspection Protocol

- Timely identification of lightning damage is critical to limit the impact of lightning damage and build a potential case for warranty claims or O&M agreement disputes.

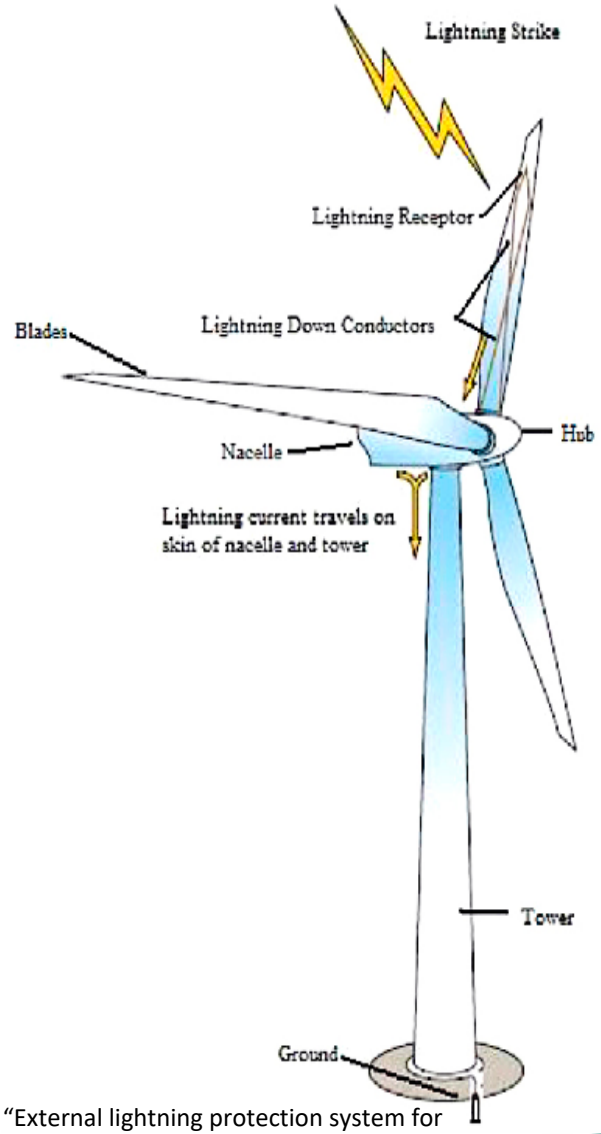
- Recommended Lightning Inspection Protocol includes:
  - Annual visual inspections of turbine blades (drone inspections are considered best practice)
  - Annual visual inspections of lightning protection system ("LPS") receptors
  - Internal inspections of 10% of the blades for the first two years of operations
  - Targeted ground-based inspections based on lightning data provided through a subscription service. Inspections should occur if lightning detection data indicates a strike within 1,000 ft of the turbine and meeting the following criteria:
    - >1 kA for Positive Strokes
    - < 25 kA for Negative Strokes
    - Strikes longer than 10 milliseconds in duration
  - Targeted inspections should be completed within two days after a lightning event.
  - All inspections should be documented in a work management system.

Tax Equity Perspective – Lightning Inspection Protocol

- Now seen as best practice (requirement) regardless of wind farm location
- Catch small issues before they turn into bigger issues
- Document damage to be better prepared for warranty/serial defect claims
- Adapt protocol over time to reflect results of inspections and overall value
- Very interested in advances in technology (mainly drones) being built into O&M plans

Turbine Technology Lightning Risk Assessment

- Lighting protection system collects electrical energy from the lighting strike and routes it safely from the blade, through the nacelle, down the tower, and to the turbines grounding system.
- Most lighting protection systems consist of the lightning receptors and down conductor(s). Consideration should be given to the sizing, number of down conductors, and the method used to transfer the current from the rotating blades to the static nacelle and tower.
- Blade composition can also affect lighting risk. Blades that contain carbon fiber are more likely to be damaged due to lightning.
- There are limitations to the testing and modeling that can be completed for lightning protections systems. The track record of any given LPS or blade is an important factor in determining technology risk.
- The Independent Engineer should review the known issues with the turbine technology.



Ayub, A. et al. "External lightning protection system for wind turbine blades - power performance." (2018).

Tax Equity Perspective - Turbine Technology Lightning Risk

- Look for the typical things – IEC LPL 1; Type Certification but **operational history is paramount** – need a system proven in the field across different lightning environments

- Need to be wary of changes or retrofits to a lightning protection system; third-party SME review is critical

- Expect Turbine Technology Review to cover depth of operational history and inform Availability and OpEx assumptions

Technical-Commercial Risk Assessment

- Turbine Supply Agreement
  - Warranty Review – is lightning damage covered under warranty?
  - Force Majeure Review – is lightning considered a Force Majeure Event?
  - RCA/Serial Defect Language Review - if there is a lightning related defect, could it be considered a serial defect?

- Operations and Maintenance Agreement
  - Exclusion review – is lightning covered under unplanned maintenance?
  - Availability Guarantee Review – is downtime due to lightning excluded from the availability calculation.
  - Force Majeure Review – is lightning considered a Force Majeure Event?

Tax Equity Perspective – Commercial Lightning Risk

- Warranties and performance guarantees are critical - would like to see OEMs stand behind product within design specs including contractual language to back it up but trend seems to be in the opposite direction with projects wearing the risk
- Believe that Sponsors need to have a concrete understanding of lightning risk and mitigants. Lightning coverage included in warranties/guarantees is strongly preferred but we understand there is a bigger picture when negotiating these agreements.
- Too easy for OEMs to claim that lightning is too difficult to define and can never protect against 100% of strikes…collecting independent data is critical
- In areas of higher lightning exposure with an unproven lightning protection system this is seen as an unpredictable risk – can result in indemnity/atypical mechanisms in contracts or, worst case, could end in passing on a deal

- Would like to see better research into damage-causing lightning strikes – thoughts on continuing current are compelling
- Open line for engaging on standards improvement / research into damage-causing strikes

Tax Equity Perspective – Insurance Lightning Risk

- Insurance market in general “hardening” due to additional claims and reacting/balancing across sectors they cover
- Traditional catastrophic perils (earthquake, named wind storm, flood) are now being broadened in scope to also include “soft” cat perils including wildfire, severe convective storms, tornado, lightning) and including sublimits in some cases as well as higher premiums
- Renewals on a 12-month basis…in other words on an interval much shorter than the expected tax equity investment so insurance is not a catch-all for lightning risk

- Start early with your insurance consultant, broker and tax equity provider to discuss project Insurance Requirements and align on where policies will likely land (balance what is needed vs what is commercially available)

Thank you!

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