Accuracy of blade detection with the Lightning Sensor & Analyzer

The Jomitek LSA principle of measurement, as a stand alone sensor, allows only for full wind turbine lightning detection. However, correlation with information on the position of the turbine blades at the time of the lightning event allows for detection of which blade (or blades) were hit by lightning as well. Please see the Jomitek Lightning Sensor & Analyzer User Manual for additional information for practical options for transferring this information from the LSA to the wind turbine control system.

Inherently this detection option will not be 100% accurate, since some situations will see two blades being equally exposed at the time of the initiation of the lightning event, or in cases of very long duration strikes, the subsequent strikes may shift from one blade to the next, as the blades rotate.

Leveraging data from extensive test campaigns of the Jomitek Lightning Down Conductor Sensor, see http://jomitek.dk/en/products/ldcs/, a representative dataset for the charge flow transferred through individual turbine blades is used in the following to quantify the propability of lightning strike for a particular blade, when performing abovementioned correlation of the blade position at the time of strike.

In lack of a concrete dataset for actual strike detection on individual turbine blades vs. blade position, the following model is based on a correlation between the amount of atmospheric charge influx (electrical current) into a turbine blade, and the probability of lightning leaders developing on the blade, to an extent where the lightning channel is fully formed, i.e. a strike occurs.

A reasonable approach to such a model is to regard the probability, P, of a strike into a specific blade as being equal to the share of the total charge influx (electrical current) during a relevant time slice. In practice, 'a relevant time slice' must ensure that the blade only move a few degrees in between measurement samples. I.e. for blade 1:

$$P_{Blade\ 1\ strike} = \frac{I_{Blade\ 1}}{I_{Blade\ 1} + I_{Blade\ 2} + I_{Blade\ 3} + I_{Hub,nacelle,tower}}$$

The Jomitek LDCS data will be processed and evaluated based the above model in the following.

Figure 1 presents data selected based on slow rotational speed of the turbine, as well as rain during the selected period of measurement. The reason for these selection criteria are (A) due to a very clean signal-to-noise ratio for charge measurement during rain, as the charge influx is significantly larger during precipitation than during dry weather, and (B) due to the fixed sample rate of the LDCS measurements allowing for a much higher granularity, when the rotational speed is low. The data was verified to be representative of both dry weather and normal rotational speeds, except for the mentioned caveats.

Note that figure 1 also presents the sum of the charge flow across all blades, which largely turns out to be at a constant level.

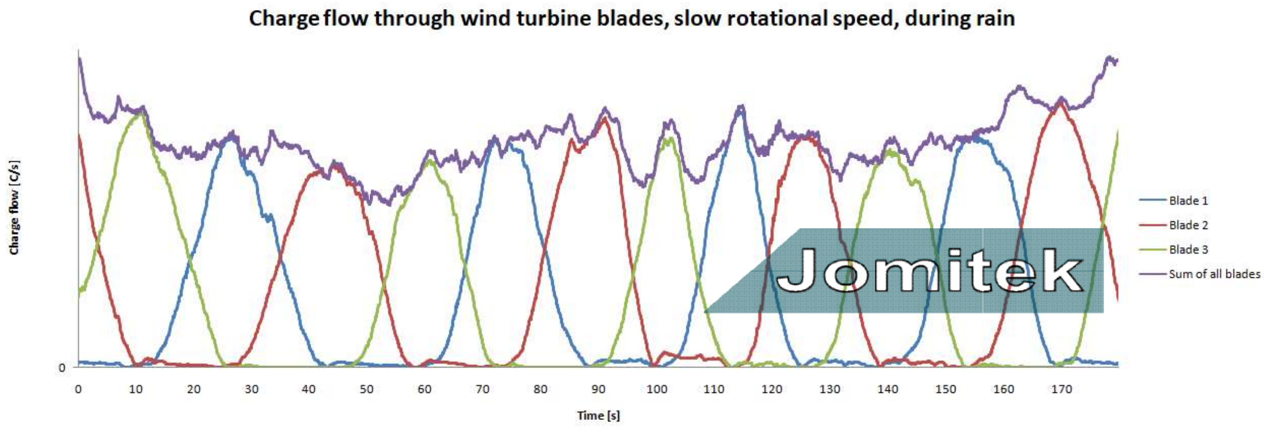

Figure 1

Real world measurements using the Jomitek Lightning Down Conductor Sensor

Application of the model to the same time series of data, for blade 1, is presented in figure 2. Note that $I_{Hub,nacelle,tower}$ is assumed to be zero in the following, however, in reality it is likely to be roughly constant, and estimated to be in the area of 15% of the peak charge flow.

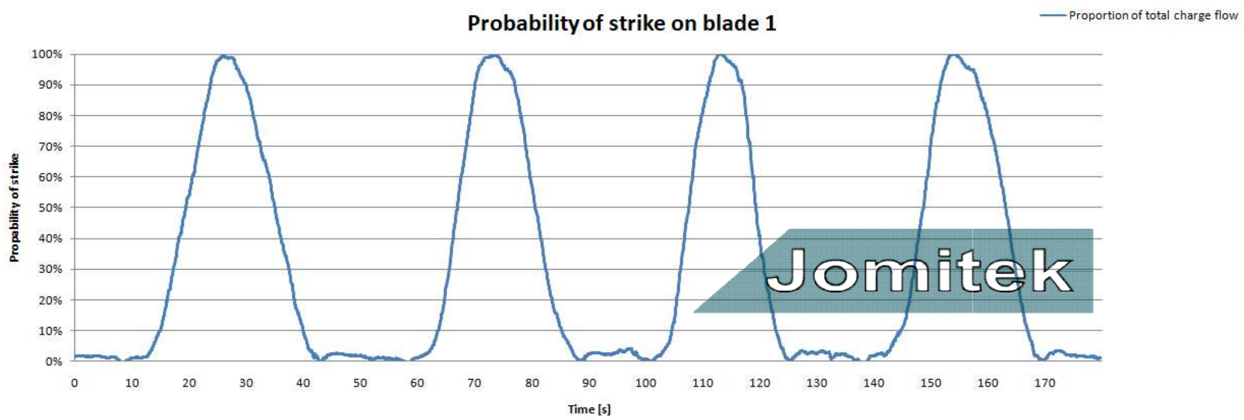

Figure 2

Strike probability for blade 1, based on data from figure 1

Correlating the datasets to the angular position of the blade, using a definition where 0° points straight up, and the direction of rotation follows a positive degree increment (i.e. rotation goes from 0° and up towards 360°), the data of figure 2 can be presented as illustrated in figure 3, with the same data also being presented in table 1.

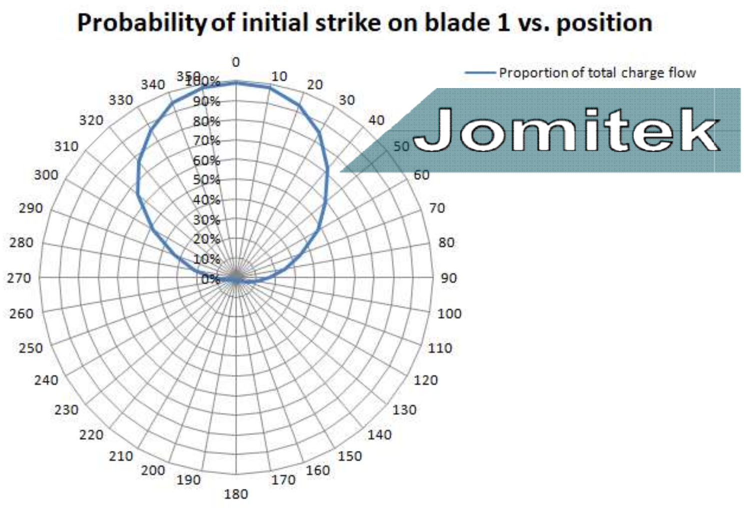

Figure 3

Angular position of blade 1 [°]	Blade 1 probability
0	98%
10	97%
20	93%
30	85%
40	72%
50	59%
60	48%
70	35%
80	25%
90	17%
100	11%
110	6%
120	4%
130	2%
140	2%
150	2%
160	2%
170	2%
180	2%
190	1%
200	1%
210	2%
220	2%
230	1%
240	2%
250	4%
260	6%
270	12%
280	21%
290	33%
300	49%
310	65%
320	77%
330	86%
340	94%
350	97%

Table 1

Assuming a rotational speed of 3.6 seconds for a full rotation - conveniently set to equate 10° / 100ms - and the average lightning event lasting roughly 200ms, including significant subsequent strikes, a reasonable assumption for the rotation of the blades during a lightning event is 20°. With this as the baseline, Figure 4 and Table 2 is created to present a practical reference for the probability of a blade being hit, as a function of the angular position of blade 1. Note that due to the 20° 'averaging' window the maximum probability for blade 1 is centered around 350° instead of 0°. Also note, that blade 2 follows blade 1, i.e. when blade 1 is in the 120° position, blade 2 will be pointing up.

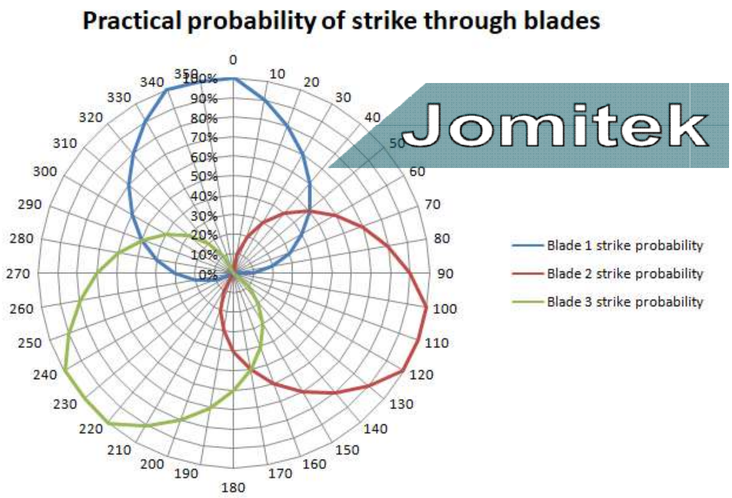

Figure 4

Note that the angular position is presented with respect to blade 1

Angular position of blade 1 [°]	Blade 1 probability	Blade 2 probability	Blade 3 probability
0	100%	0%	0%
10	90%	10%	0%
20	80%	20%	0%
30	70%	30%	0%
40	60%	40%	0%
50	50%	50%	0%
60	40%	60%	0%
70	30%	70%	0%
80	20%	80%	0%
90	10%	90%	0%
100	0%	100%	0%
110	0%	100%	0%
120	0%	100%	0%
130	0%	90%	10%
140	0%	80%	20%
150	0%	70%	30%
160	0%	60%	40%
170	0%	50%	50%
180	0%	40%	60%
190	0%	30%	70%
200	0%	20%	80%
210	0%	10%	90%
220	0%	0%	100%
230	0%	0%	100%
240	0%	0%	100%
250	10%	0%	90%
260	20%	0%	80%
270	30%	0%	70%
280	40%	0%	60%
290	50%	0%	50%
300	60%	0%	40%
310	70%	0%	30%
320	80%	0%	20%
330	90%	0%	10%
340	100%	0%	0%
350	100%	0%	0%

Table 2

It is the recommendation of Jomitek to make use of Table 2, when implementing the logic for assigning which blade was hit, when based on Jomitek LSA measurements. In those cases where the probability is spread across 2 blades, the particular lightning event - from a principle of being cautious - may be assigned equally to both. Alternatively - from a more practical / statistical perspective - the event parameters may solely be assigned to the blade with the highest probability, with the special case of 50/50 being assigned to the leading blade, i.e. the one in the ~50° position (which is most likely to be hit by the main strike). Using the latter assignment approach will result in an overall accuracy of 82%. Using the first approach, an assurance of reporting for all likely hit blades reach 97%, based on the modeling used. Both of these accuracy figures assume that lightning is equally likely to occur at any given orientation of the wind turbine blades.

At present, Jomitek has no statistical material to support a higher probability of lightning being initiated when one of the blades reach the top position towards the sky, than at the 60°/300° position. From an intuitive point of view, it is however likely that the difference in maximum height, typically in the area of 30-40m for medium/large wind turbines, constituting about 1% of the potential difference height between the charged sky and ground (i.e. height of lightning ~3-5km), may be the 'last drop' needed for the lightning channel to be created. As such, **the overall accuracy may in reality be even better**, if there is a tendency for the lightning event to occur around the top position of a blade.

Note that, with the assumption of $I_{Hub,nacelle,tower} = 0$A, the presented figures and tables assume that a lightning will always strike one or more blades. In reality, following the logic of the model, and the estimate of the $I_{Hub,nacelle,tower}$ share of the total charge flow being ~15%, there is a corresponding risk (i.e. ~15%) of lightning striking the turbine (most likely the hub, or top of the nacelle) without passing through the blade lightning down conductors.

Comments regarding the practical value of blade detection of lightning strikes.

In the understanding of Jomitek, the value of blade specific detection of lightning strikes lie mainly in cases with rare and powerful strikes, where it is reasonable to focus inspection efforts on the specific blade affected. This can likely reduce some of the inspection cost, compared to inspection of all 3 blades - though the main cost usually lies in getting on site.

In general, statistically speaking, the majority of cases will see a high likelihood of multiple minor-to-medium strikes on all blades, and it is either the aggregation of lightning events or a single powerful strike which prompts the need for on site inspection. In such cases, while blade specific detection is a nice-to-have, it will be prudent to inspect all blades while on site. As such, there is no effective cost reduction tied to blade specific detection.

On this basis, and considering the risk of wholly or partly missing lightning strikes with a blade lightning down conductor based detection system, a system based on full tower detection was considered superior in the initial design phase of the the Jomitek LSA development. Both in terms of detection capabilities, the related installation cost of the sensor system, and the implication for O&M costs.

Feedback, as well as questions and comments to this development note is welcome. Please see www.jomitek.dk for contact information.

This development note was created by Jomitek on October 24, 2022.