Lightning: manageable threat or force majeure for wind turbines?

Lightning strikes pose a significant threat to wind turbines, potentially causing catastrophic damage. However, this risk can be effectively managed through systematic lightning protection system (LPS) inspections. This article explores the importance of LPS inspections, details methods employed by Aerones, and presents a data-driven approach to optimizing inspection frequency based on various factors.

Lightning, a naturally occurring electrostatic discharge, presents a major challenge for wind turbine operators. Its immense heat, reaching more than 27 000°C / 50 000 °F, exceeding the sun's surface temperature five times, can severely damage turbine blades. Our inspection data reveals a concerning statistic: nearly 20% of turbines exhibit issues with their LPS, jeopardizing safety.

The role of lightning protection systems

A lightning protection system (LPS) safeguards wind turbines by channeling lightning energy away from the blades and safely grounding it. Ideally, during a strike, the energy dissipates harmlessly. However, reality paints a different picture. Over 20% of turbines have LPS malfunctions, often due to cable breaks or oxidation, increasing resistance and compromising protection. This issue is prevalent across all manufacturers.

Inspection process and importance

Upon commissioning, a properly functioning LPS exhibits low resistance, ensuring safe lightning dissipation. However, deterioration sets in over time. Common issues include open circuits, receptor damage, oxidation, and blade erosion, which disrupts the intended lightning path.

Regular LPS inspections are crucial for early detection and rectification of these problems. Aerones utilizes a robotic system for efficient and accurate resistance measurements at each receptor on the blade. This comprehensive approach ensures no vulnerable spots are missed.

It is not enough to only check continuity. Resistance must be measured as well. Blades with increased LPS resistance have a much higher chance of being damaged by lightning even if they have continuity.

Consequences of neglected LPS

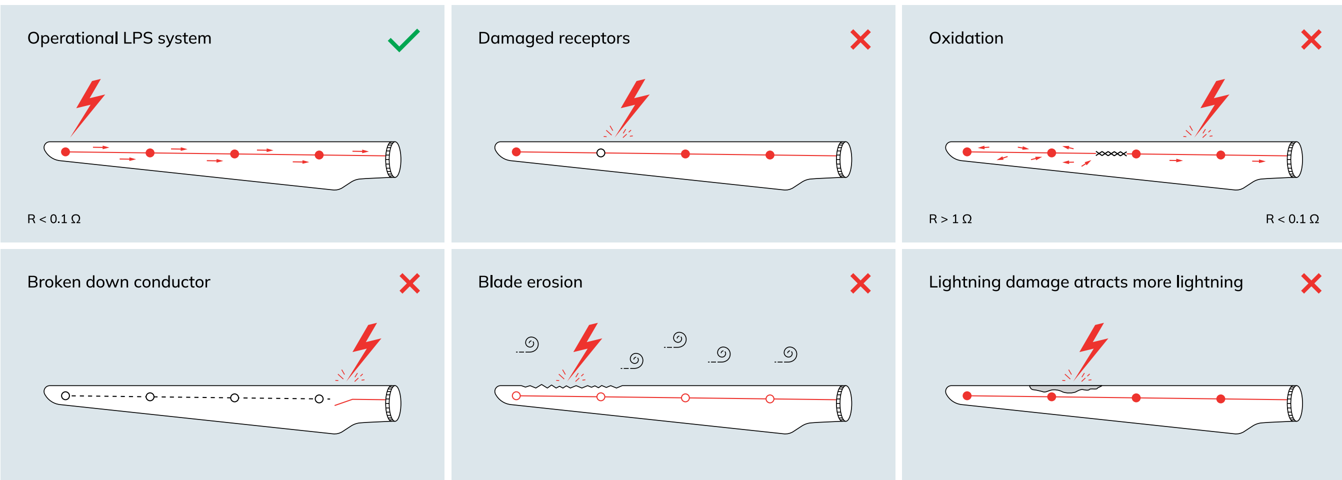
- Oxidation: increased resistance encourages lightning to bypass receptors and strike the blade directly, causing significant damage.
- Broken down conductors: complete system failure results in catastrophic damage, especially for older turbines with non-replaceable blades.
- Erosion: significant blade erosion disrupts airflow, potentially causing lightning to strike the blade surface instead of receptors.

Lightning's 'memory'

Lightning tends to favor previously struck locations, due to conductive soot that is created from burned materials that creates a path of least resistance. This increases the risk of recurring damage in the same area.

Analogy: water pipes and resistance

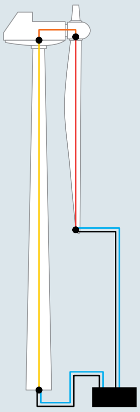
The LPS system's resistance can be compared to water flow in pipes. Low resistance signifies unimpeded flow.



Typical causes of lightning damage

Resistance checking

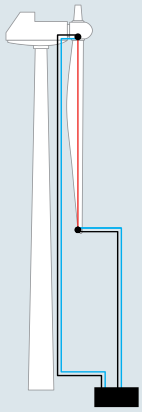
Full Loop



A full loop measurement is a standard LPS inspection procedure. For a full loop measurement, a bridge has to be made between the blade root and grounding in the nacelle. One LPS probe is grounded at the tower base, and another probe on the LPS robotic system is connected to blade receptors. Both LPS probes are connected to the micro-ohmmeter in the operation center on the ground. Bridge connection resistance has to be subtracted from the obtained measurement to obtain the WTG full loop measurement.

Resistance checking

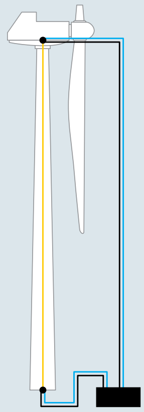
Blade Measurement



For blade measurement, the LPS troubleshooting probe is lifted to the nacelle and connected to the blade root. Another LPS probe is connected to the blade receptors using the LPS robotic system. Both LPS probes are connected to the micro-ohmmeter in the operation center on the ground.

Resistance checking

Tower Measurement



The LPS probe is grounded at the tower base. The LPS troubleshooting probe is lifted to the nacelle and connected to the ground connection in the nacelle. Both LPS probes are connected to the micro-ohmmeter in the operation center on the ground.

Increased resistance creates bottlenecks, potentially causing pipe bursts, similar to flashovers in the LPS that can damage blades. Very high resistance denotes a complete disconnect, preventing energy dissipation and leading to catastrophic blade damage.

Aerones' inspection technologies

For a comprehensive assessment of wind turbine blade health, we recommend combining external inspection via autonomous drone, internal visual inspections using a crawler and a full LPS resistance check. Aerones customer portal combines this information in one simple view highlighting any defects and offering recommendations for repairs.

A Full Loop Conductivity Test measures the conductivity of the entire lightning protection system, encompassing the receptors, cables, and grounding components. It provides a holistic assessment of the system's functionality and identifies any weak points that could hinder proper lightning current dissipation. This approach ensures that all elements of the LPS, from blade tip to foundation, are working cohesively to safeguard the turbine.

Aerones has developed a robot capable of checking resistance for each and every receptor on the blade. It's a relatively fast and the most reliable process compared to other methods. The robot approaches the blade from both sides and takes resistance measurements multiple times just to make sure it's accurate.

The robot uses two rotating needles that can pierce through paint or coating to access the metallic head of the LPS receptor. This way it ensures there are no false-positives as we check the connection between the needles before full measurement is done.

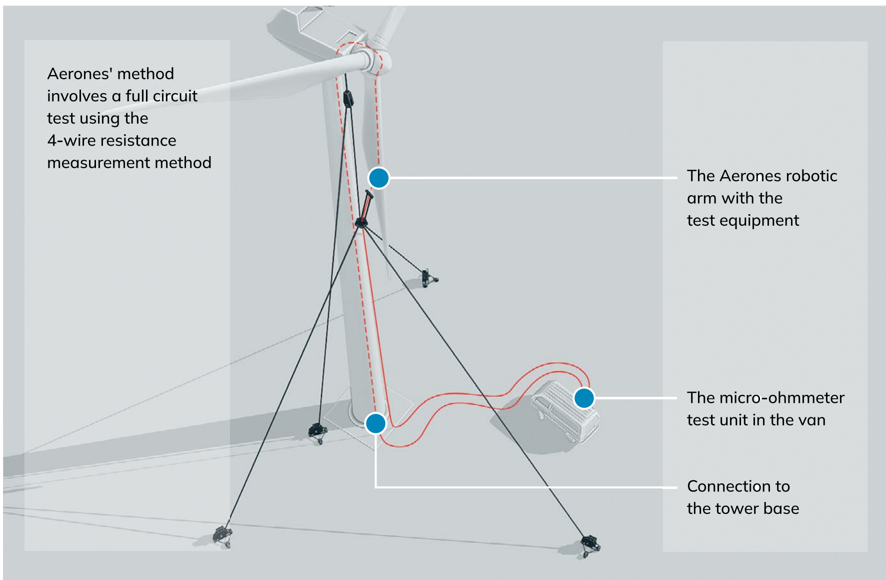
We also use the 4-wire resistance measurement method. The robot is lifted up using a winch system. We also make sure that the resistance of the actual cables used is taken out from the equation when we are testing the full system, the blade, the nacelle, and the tower to make sure that the whole system is working. We use bypass cable to directly connect the blade and tower and bypass slip rings and spark gaps.

We have also developed an open circuit finder that is used to pinpoint the exact location of an open circuit from within the blade. Primarily, it is used as an additional test when the ohmmeter shows open circuit measurement. If necessary, Open Circuit Finder can be used as a handheld device to search for faults in the root section of the blade. A beeping sound identifies the exact location of where the fault has taken place.

It is a simple process but a very important one that dramatically reduces the time needed to locate the damaged part of the down conductor allowing technicians to carry out repairs quickly and reduce turbine down time.

Beyond LPS: drainage hole cleaning

Water accumulation in blades can add significant weight, cause vibration and exacerbate lightning damage. Oil leaks combined with stagnant water can lead to severe damage if struck by lightning, as the rapidly heated liquid expands and explodes the blade tip. Aerones' robots perform drainage hole cleaning alongside LPS inspections.



Aerones 4-wire resistance measurement process is fast and reliable

Predictive maintenance using data

Aerones leverages inspection data from around the globe to develop predictive maintenance models. These models consider factors like OEM data for specific wind turbine model information; statistical analysis of commonly encountered issues; and lightning density by looking at historical lightning strike data for the region.

These models, combined with on-site inspections, enable us to calculate the optimal inspection frequency for each wind farm.

Factors affecting inspection frequency

Several things can determine the inspection frequency, including results from previous inspections for the same turbine model globally and the age of the turbine, as older turbines have increased chance of lightning damage. Time since last repair is also important, as the chance of lightning damage increases over time, plus lightning density at the location, as more lightning strikes increase chance of damages. Finally, turbine height and proximity to sea can have an effect, as higher turbines and those near the sea are more susceptible to erosion and require more frequent inspections.

By considering these variables, Aerones calculates the likelihood of lightning damage for each turbine. This evaluation guides the recommended inspection frequency, optimizing resource allocation and minimizing turbine downtime.

Customized inspection schedules

Instead of a generic approach, Aerones tailors inspection schedules based on individual wind farm needs. This approach considers factors like location, lightning density, and historical inspection findings. For example, LPS inspections might be necessary every four years in Texas and every seven years in Canada.

Conclusion

Global warming is expected to increase lightning activity by 12% for every 1°C rise, potentially causing a 50% increase in lightning strikes for some countries by the end of the century. However, lightning risk for wind turbines is not an inevitable force majeure event; it can be effectively managed through systematic LPS inspections.

The frequency of these inspections can be optimized through data-driven approaches, considering various factors like location, historical data, and turbine characteristics. Aerones utilizes this approach to create customized inspection schedules, ensuring optimal resource allocation and minimizing turbine downtime.

By transitioning from guesswork to data-driven decision-making, we can ensure the future of wind energy is reliable, efficient, and cost-effective.

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