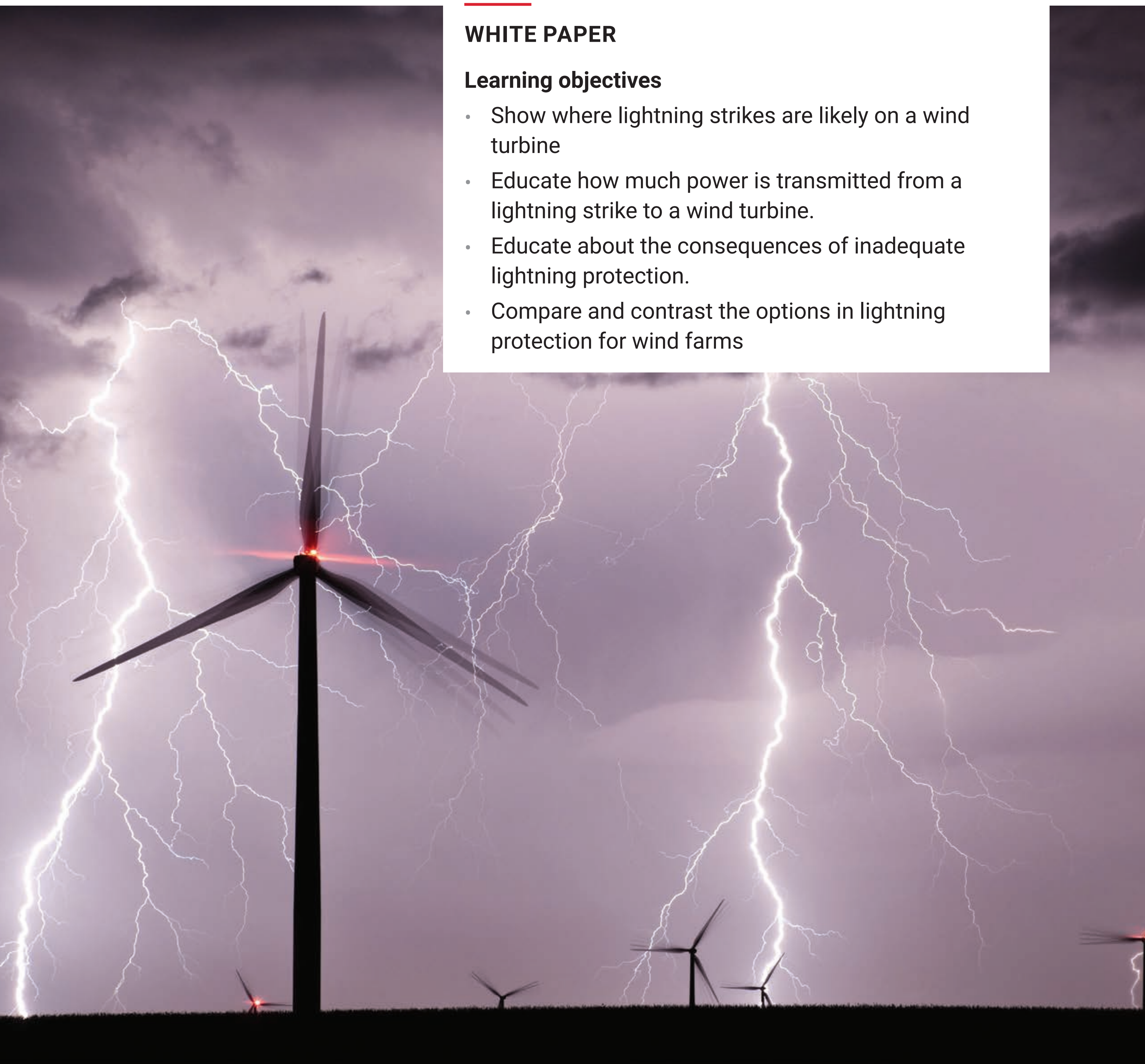
We connect and protect

Improved Performance of Lightning Protection for the Wind Industry

WHITE PAPER



Learning objectives

- Show where lightning strikes are likely on a wind turbine
- Educate how much power is transmitted from a lightning strike to a wind turbine.
- Educate about the consequences of inadequate lightning protection.
- Compare and contrast the options in lightning protection for wind farms

Abstract

Based on studies and computer modeling the wind industry can improve the level of protection from lightning strikes. Studies have shown that the tip of the blade is most likely to be struck, but attachment points can also be found along the length of the blade. The nacelle is also highly susceptible to receiving a lightning strike. It is typically one of the last systems considered in the design, but a lightning protection system can reduce overall operational costs if implemented correctly.

An average bolt of lightning carries an electric current of 30 kA and transfers 15 coulombs of electric charge. These strikes can generate enough heat to catch the blade or nacelle on fire causing significant damage, up to a total loss of the tower. Roughly twenty-five percent of wind turbine insurance claims are related to lightning strikes.

Recent advances in technology have led to improved transmission and heat dissipation of this destructive energy for the wind industry. Conventional lightning protection is susceptible to internal attachments (punctures to the blade) because electrical connections to the down conductor are not insulated. Newly developed systems can practically eliminate these attachments due to robust insulation and improved installation methodology.

Extended Abstract

Lightning surveys in the field as well as computer modeling have shown that many lightning protection systems on wind turbine blades are inadequate. Many of the systems that are in the field currently protect at or near the tip of the blade, but do not account for strikes occurring on the blade toward the hub (Figure 1 & 2). Figure 1 shows that the probability of a strike bypassing the blade tip increases as the intensity of the strike decreases. This can be confirmed via field evidence with blade punctures and fires that occur along the length of the blade. Figure 2 shows that the rear of the nacelle is also very likely to get struck.

As stated above, some systems in the industry today rely on just protecting the tip of the blade. Other designs have pairs of receptors on opposite sides of the blade located at various locations along the blade. These additional receptors increase the likelihood of capturing all strike intensities and preventing damage to the blade.

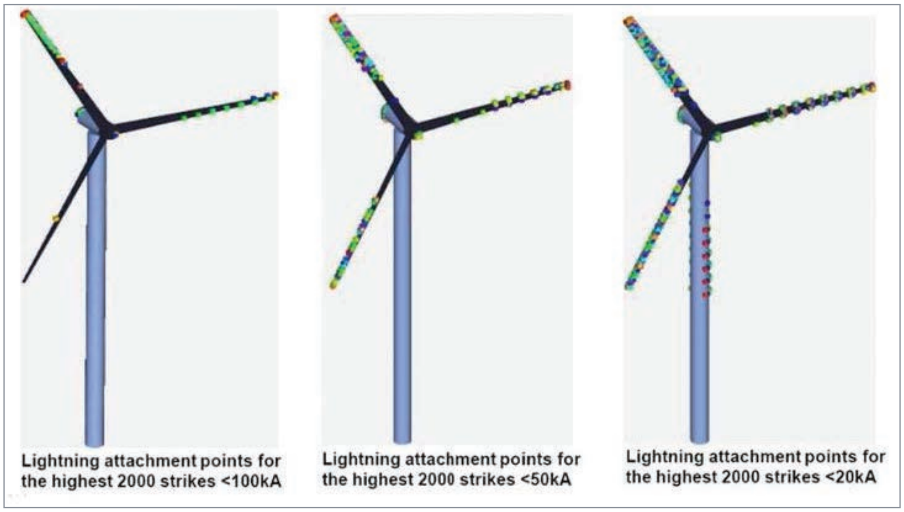


Figure 1: Lightning attachment model

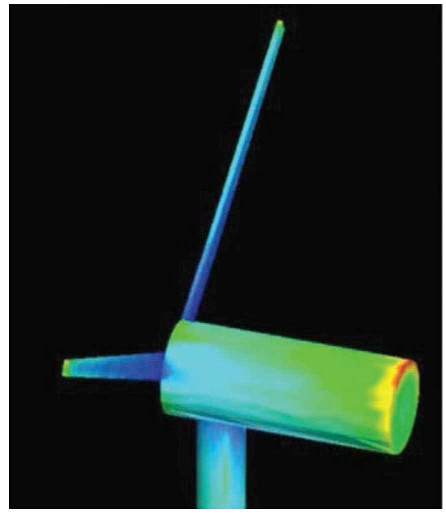


Figure 2: Electric field strength distribution

Protection methods to carry the current to the ground have been in use for many years, but the technology is generally the same one currently used for skyscrapers and telecommunication towers. The nacelle typically utilizes a Franklin rod (air terminal) to capture the strike and transfer it to the ground through the tower into the earth. The dynamics of the wind turbine blade continually change the area likely to get struck as the blade's orientation is changing due to inherent rotation.

Any of these areas which incur an attachment can cause minor damage to total loss if the blade or nacelle catches fire from improper lightning protection. **Photo 1** to the right shows a complete blade loss as the result of a lightning strike. It is unclear if this was struck at the tip or somewhere along the blade. This could have been avoided if proper lightning protection methods and equipment had been used during the design phase.

Lightning protection is often an afterthought in total wind turbine design. Most design considerations are given to airfoil geometry to optimize efficiencies that will produce the most power. This is key to the success of the industry, but directing a small amount of design time toward lightning protections could offset the overall cost to the end user. It is typically much less than 1% of the overall cost to produce the wind turbine but can save hundreds of thousands of dollars if not millions from insurance claims.

The power generated during a lightning strike is one of the most powerful events in nature. An average lightning event carries an electric current of 30 kA and transfers 15 coulombs of electric charge. In extreme cases, this can go up to and exceed an electric current of 120 kA and transfers 350 coulombs of electric charge. This energy must be captured and transferred very quickly to avoid heat buildup, which can damage the structure in and around the strike. To transfer this energy most efficiently, a copper conductor with a minimum cross-sectional area of 50 mm² is required by IEC 61400-24. Aluminum conductors are also allowed but are typically used for reducing overall costs and require a minimum 70 mm² cross-sectional area.

Photo 1: consequences of lightning strikes on wind turbines

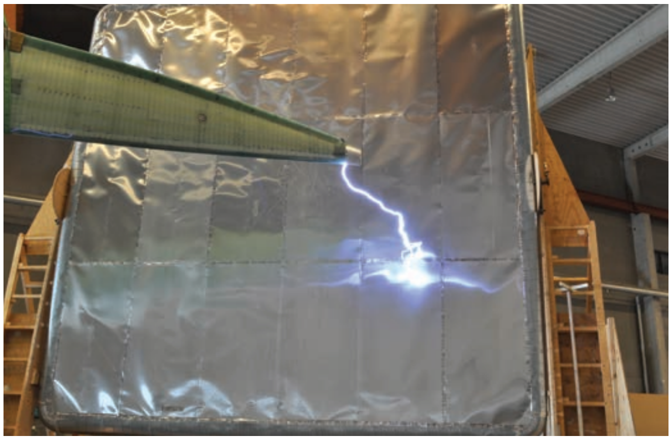


Photo 2: High voltage testing of tip receptor

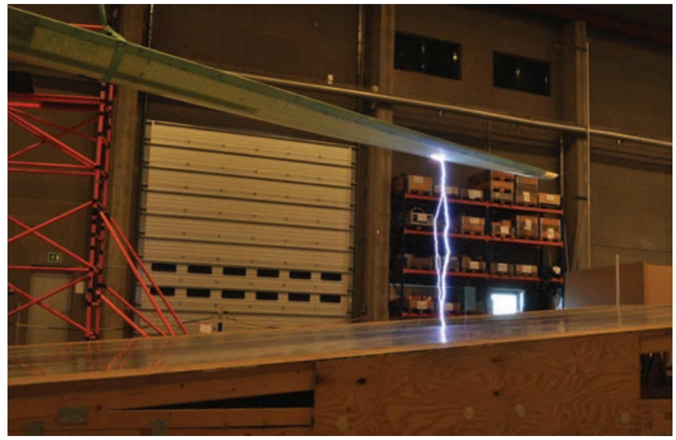


Photo 3: High voltage testing of side receptor

Photos 2 and 3 show lab testing of attachments to the tip receptor (Photo 2) and side receptor (Photo 3). These photos were taken with the shutter open to capture the strike. These strikes were of great magnitude to meet the Japanese standard which is 200 kA @ 20 MJ/Ω. The IEC standard 61400-24 recommends 200 kA @ 10 MJ/Ω of protection.

Lightning strike damage accounts for roughly 25% of the total insurance claims for wind turbines. This is a huge cost driver for managing and owning a wind farm in areas that are prone to lightning areas such as the South and Plain regions in the United States. Many of the wind farms in the US are in these areas.

Lightning protection system designs vary between blade designers from very simple to very elaborate. Figure 3 shows one of the simpler designs that uses a side receptor near the blade's tip to prevent damage. This does not cover strikes that are further down the blade based on the modeling and field data previously discussed. Another method utilizes multiple side receptors and a tip receptor as shown in Figure 4. These systems can be configured in pairs or individual receptors down the blade in as many locations as desired by the blade designers. The optimal configuration is with three receptor pairs with at least five meters of separation between the sets. The tip receptor will capture the largest strikes that the blade will encounter.

The newest lightning protection system designs have come from the drive to build bigger turbines. As the length of the blades increases, the push for lighter, stiffer materials has led to more blades using carbon fiber in the blade walls. The carbon fiber is inherently conductive and thus needs to be properly bonded to the lightning protection system to prevent flashover damage. The industry has begun using copper mesh over the carbon fiber (Photo 4) as a path to transfer the current from the outside of the blade to the internal lightning protection system and down conductor.

Insulation is another factor in lightning protection that has historically been overlooked. This has been shown in testing where strikes penetrate through the blade wall and attach to the connections between the receptors and the conductors. This will carry the current to the grounding system but can have catastrophic consequences resulting in complete turbine failure from the point at which the lightning attached to the system.

The system in Figure 4 overcomes this issue with a fully insulated design. The “plugs” that attach to the side receptor sockets are molded with all the components, including the conductor, which completely insulate the conductive materials. The sockets are made of a polymer which also acts as an insulator once the installation is complete. Only the side receptor disk is conductive and will transfer the energy down into the ground safely. The system was tested at 200 kA with less than a 53,6 F 12°C rise in temperature to the surrounding area. This is an important point; just because a receptor has an attachment doesn’t mean that it will prevent damage. Small cross-sections in connections can result in heat intensification and cause fires.

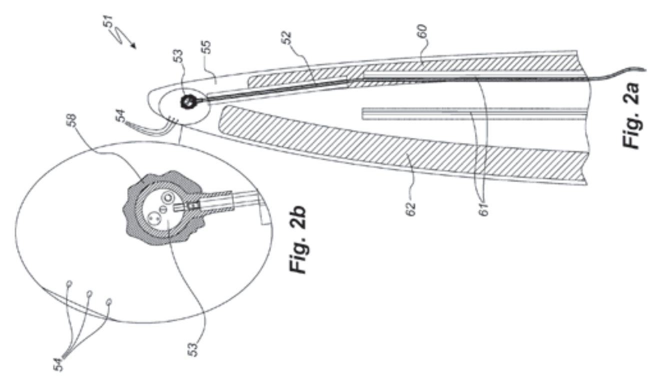


Figure 3: Labour-intensive installation for blade manufacturers

Installation and quality of installation are other topics to cover when it comes to incorporating any of the systems already discussed. The system in Figure 3 is highly labor-intensive for blade manufacturers. Side receptors must be located from the outside of the blade after the blade has been closed. This leads to rework as the team must use locating devices and layouts to locate them. The majority of operators can locate the receptors or receptor blocks but may drill and tap the hole incorrectly. This leads to costly reworks and potential quality issues. The paste used to hold the receptor blocks in place can cover the conductive surfaces and when the down conductor cable is attached can cause a major performance problem. Rather than the strike energy going directly to the down conductor it could arc over the paste causing a flash and potential fire.

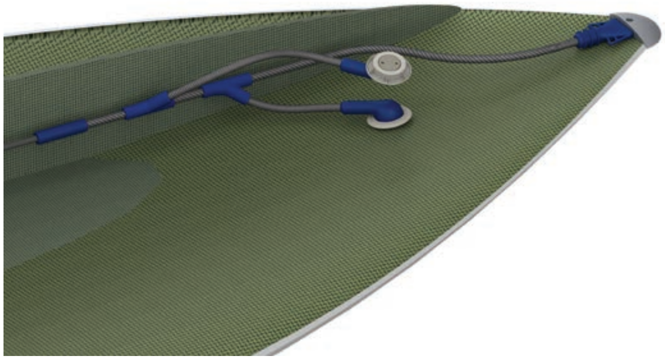


Figure 4: Illustration of nVent ERICO lightning blade protection

The plug and socket installation (Figure 4) requires very little skill as the socket is laid onto the blade mold and the blade is built up around it. The plug is connected to the socket easily on the first side and requires a simple tool to connect to the opposite side when the blade is closed. There is no guesswork as to where the receptor block is located and is installed in minutes as compared to hours for the system in Figure 3.

Maintenance is not seen as a concern upfront as this tends to be managed by the end user. Most of the simple systems are not easily maintained as they are unable to be accessed without cutting open the blade to be replaced when damaged. This is very difficult as crews must rappel down the blade while installed and cut open, splice, replace, and seal the blade. Getting the tools required for the damaged area(s) can be a daunting task. In some cases, a composite section may need to be installed to replace the damaged area which could reduce the efficiency of the turbine as it is getting fabricated. Photo 5 shows a two-man crew inspecting and repairing some damage near the tip of a blade.

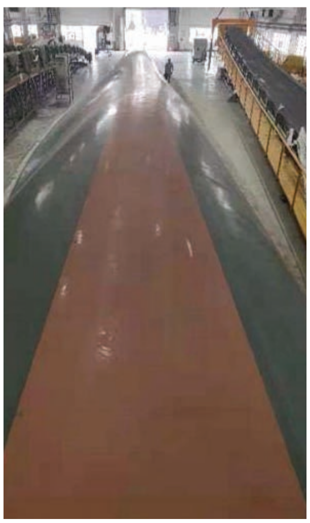


Photo 4: Copper mesh installation

Maintenance costs are a minimum of $10,000 (USD) to repair even minor lightning damage, plus the downtime costs associated with no energy production. Total blade or even turbine loss from a strike far exceeds $100,000 which could have been prevented with less than $3,000 with proper lightning protection.

The plug and socket system addresses the issues with field maintenance by simply screwing a new receptor into the plug. This can be done with a face spanner wrench and can be tightened by hand or torque wrench (preferred method). The methods which have receptor blocks tend to have receptors that are custom-fit based on the installation. There could be various sizes of receptors on a single blade, which requires the crew to carry more weight and opens up the opportunity for incorrect receptors to be installed.

Many systems can protect a wind turbine, but designers should make the decision that works best for the entire service life of the project. All the factors above can be daunting when inadequate resources are allocated to design the appropriate lightning protection system. Not installing a lightning protection system is also an option but will have severe consequences. With technologies advancing so quickly at times project managers need to address these new and innovative ideas to differentiate their project from the competition. Insurance companies are always looking to reduce their risk. These newer technologies will help them do this and reduce premiums, which leads to a more profitable business model for the wind turbine industry.

Photo 5: Blade damage repair

Acknowledgments

Photo 1 by Darren DeJong
https://www.wind-watch.org/news/2012/08/06/fire-in-the-sky-lightning-strike-sparks-buffalo-ridge-turbine-blaze/

Figure 3 – Google patents
http://www.google.com/patents/EP2226497A1?cl=ko

Photo 5 – Rope Partner
https://www.ropepartner.com/services/wind-turbine-blade-repair/