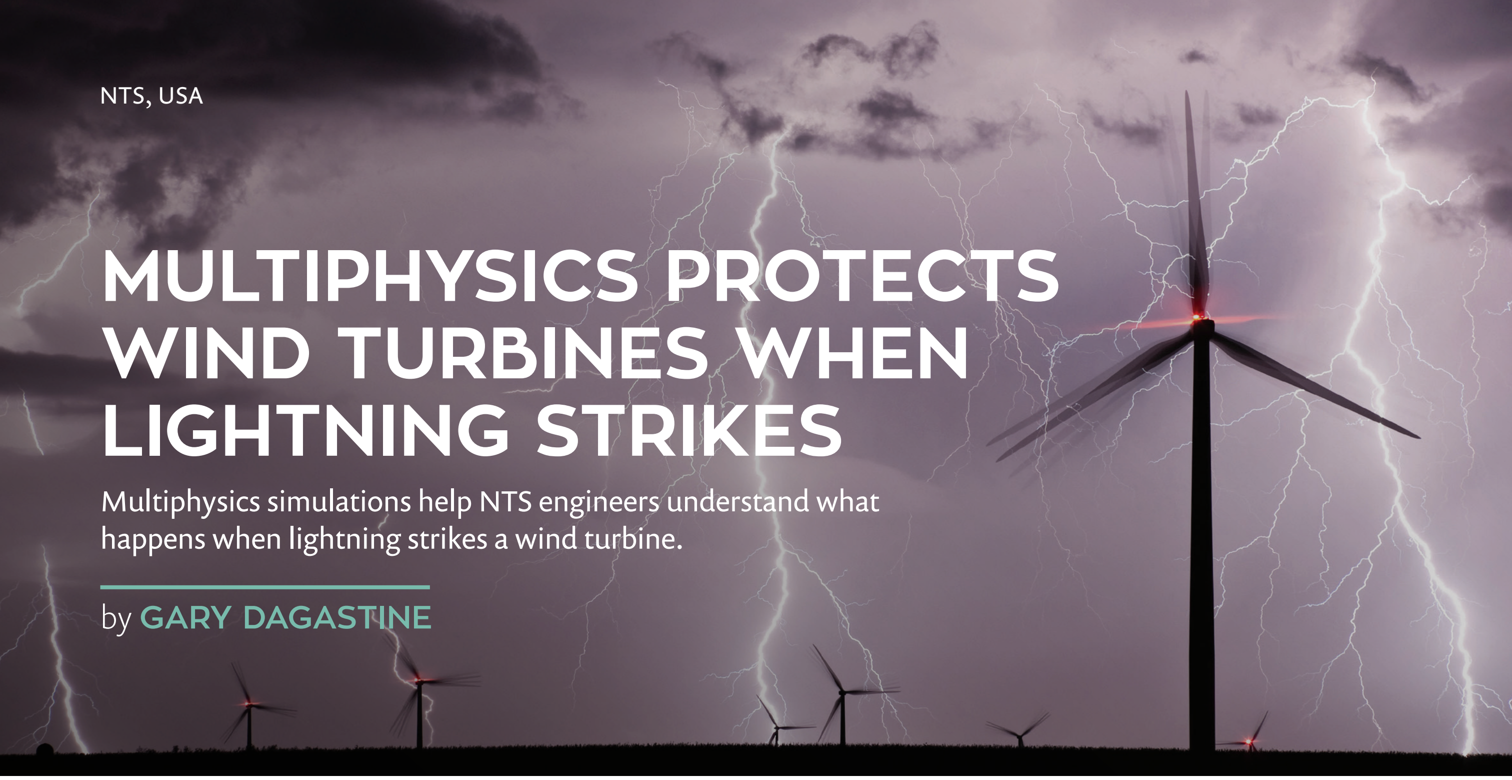

MULTIPHYSICS PROTECTS WIND TURBINES WHEN LIGHTNING STRIKES

Multiphysics simulations help NTS engineers understand what happens when lightning strikes a wind turbine.

by GARY DAGASTINE

As the world moves to reduce its dependence on fossil fuels, the global market for wind turbines is growing, projected to reach around $70 billion dollars annually in the next few years. While wind power on such a scale is a great achievement, another powerful force of nature is preventing the industry from reaching its full potential: lightning.

Lightning strikes are the single largest cause of unplanned downtime in wind turbines, responsible not only for the loss of untold megawatts of power but also for huge operation and maintenance costs.

Wind turbines are particularly susceptible to lightning strikes because of their great heights, exposed locations, and large rotating blades. Lightning can wreak havoc, both directly and indirectly, on virtually all wind turbine components, including blades, control systems, and other electrical components. Repair is not only expensive but also physically challenging given the logistical constraints.

FIGURE 1. High-voltage generator (2.4 MV Marx generator) operated by NTS.

Lightning Technologies, an NTS company, is a world leader in the design and validation of sophisticated lightning protection systems for the aerospace industry, including aircraft, space vehicles, and launch facilities. They also developed systems for wind turbine farms, industrial complexes, golf courses, theme parks, and other high-risk locations.

Engineers at NTS are actively involved in the committees that form the International Electrotechnical Commission (IEC) , which define the lightning levels and situations that blades must endure. Industry regulations such as IEC 62305 require wind turbine manufacturers to incorporate lightning protection designs into their blades. For maximum protection, it's essential to know how much lightning current is likely to flow through a blade following a lightning strike and precisely where it will flow. The problem is that simple assumptions about the behavior of lightning current often lead to inaccurate conclusions.

⇨ DEEP INSIGHTS INTO LIGHTNING CURRENT

NTS operates one of the most complete lightning simulation laboratories in the world from an 18,000 ft^2 facility in Pittsfield, MA, USA, featuring 14- and 25-foot tall lightning generators capable of generating as much as 2.4 MV (Figure 1).

NTS has been involved in the research and development of protection designs for wind turbine blades for decades. Because wind turbine blades are airfoils, the company's deep knowledge base of aerospace applications is directly transferrable.

Justin McKennon, who leads the Modeling and Analytical Team at NTS Pittsfield, said that traditional wind turbine protection schemes consist of a surface protection layer (SPL) covering the lightweight, high-strength carbon fiber composite blades. Often, the SPL consists of a conductive mesh meant to safely carry lightning current from the point where it "attached to"

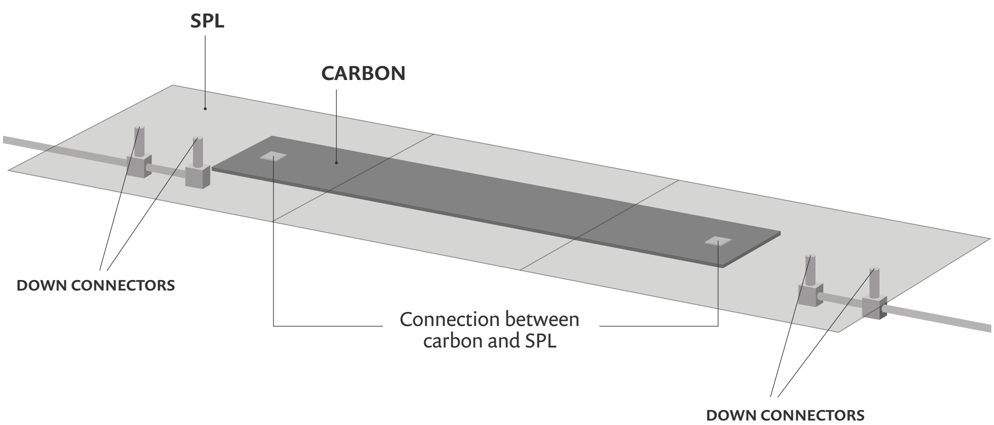

FIGURE 2. Geometry of the thin aluminum surface layer protection (SPL) placed on top of a carbon stack.

(e.g., hit) the blade and then from the root to the ground.

"Many blade architectures feature stacked carbon fiber structural layers running parallel to the SPL, with periodic electrical connections between the stack and the SPL all along the blade's length," McKennon explains. "This is done to prevent a high voltage potential from developing between the two, because if that should happen, arcing could occur and damage the blade. However, while these electrical connections can reduce voltage, they also allow current to flow in the carbon, which creates additional design considerations."

Understanding a carbon stack's ability to carry various amounts of current, along with other factors such as likely attachment points and puncture possibilities, isn't trivial. McKennon said that given the cost to physically test these blades, some of which are 70 or more meters long, the numerical modeling of lightning effects has become a crucial part of the design process.

"Because of the complexity of the physics involved, though, it's easy to make improper assumptions that can have a large effect on the accuracy of the models," McKennon says.

➪ SIMULATION REDUCES OVERENGINEERING

> "Our ability to rapidly simulate and turn around models greatly reduces program risk, and allows for engineering level data to be obtained almost in an on-demand fashion."

One common but improper assumption is to assume that the carbon stack's conductivity is the same in all directions, even though in reality there could be significant differences in carbon's conductivity along different directions. Figure 2 shows the geometry of a carbon stack placed 5 mm below a 500-µm-thick SPL mesh made from an aluminum sheet, whose conductivity is set according to experimental measurements. The carbon's conductivity is also set according to experimental values, both its idealized isotropic and realistic anisotropic behavior have been considered in the COMSOL model.

An analytical representation of an IEC-standard current waveform is used to inject current into one end of the SPL. The current exits at the opposite end through a down conductor, which is made of copper, as are all of the connections to the carbon.

To investigate his designs and model the propagation of electromagnetic pulses, McKennon solved a time-domain wave equation for the magnetic vector potential in the COMSOL Multiphysics® software. The results enabled him to determine the associated currents, electric fields, and other values at those points, providing insight into the current's overall behavior throughout the entire structure.

The isotropic case underestimates the amount of current traveling through

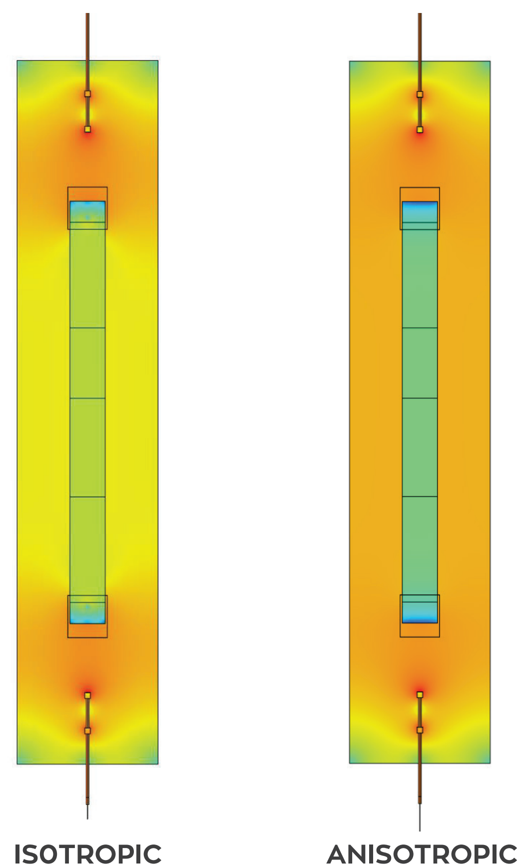

FIGURE 3. Simulation results showing that the amount of current in the SPL in the idealized isotropic case is significantly less than the realistic anisotropic case.

the SPL, implying that more current is traveling in the carbon and not in the SPL (Figure 3). Carbon is made up of many layers of individual fibers. It is very conductive in the fiber direction, but getting current into and out of the carbon is very challenging. If too much current has to pass through an interface between the carbon and something else, many of the individual fibers in the carbon can be burned away through heating and/or arcing (Figure 4). Carbon bears the primary structural loads, and damage here greatly reduces the lifetime of the blade and, in some cases, can lead to catastrophic loss of the blade. More current in the carbon is something engineers want to seriously avoid.

The isotropic case grossly overestimates the amount of current in the carbon because it ignores the very real orientation-dependent resistances in the carbon (Figure 5). Thus, given its large volume and comparable length, the carbon seems to be a more preferred current path than the SPL, even though it isn't in reality. Such an overestimate would introduce additional challenges that are not present, thus slowing down the development process and leading to an overengineered product.

McKennon says, "In modeling such complex physics, you really have to know what's important and what's just noise, and you must build your model carefully in a step-by-step fashion so that no errors or false assumptions are introduced that can significantly affect your results."

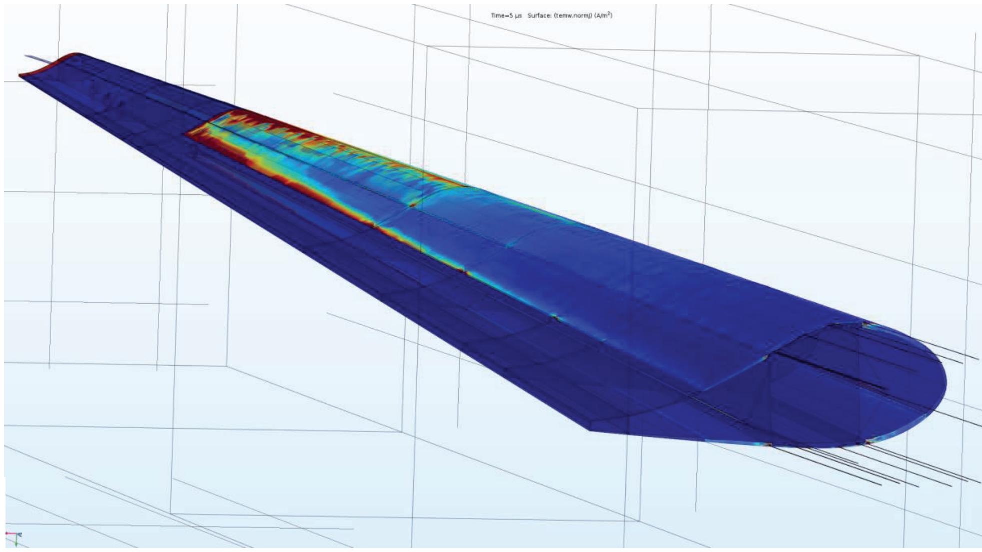

FIGURE 4. Simulation results showing the current density on a sample wind turbine blade made of several carbon stacks.

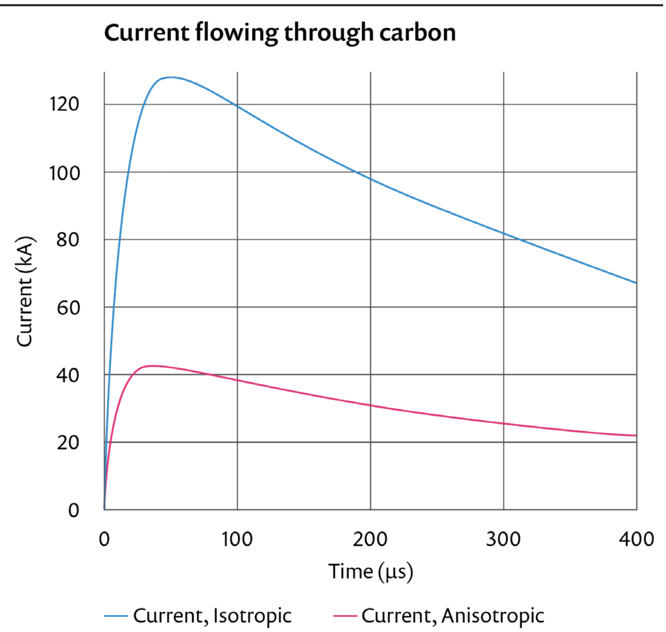

FIGURE 5. A plot demonstrating the current levels in the isotropic and anisotropic carbon cases.

⇨ RELIABLE RESULTS FOR BUSINESS DECISIONS

"Our ability to rapidly simulate and turn around models greatly reduces program risk and allows for engineering level data to be obtained almost in an on-demand fashion," says McKennon. "Rather than spending considerable amounts of time and money fabricating complex test articles, we can use COMSOL to simulate the physical phenomena and drastically reduce the problem scope for these projects. In many cases, critical data simply cannot be measured on real test articles, which requires simulation and analysis to fill in these holes."

"Time is money in our industry, and our customers are very pleased with the service we're able to provide thanks to these capabilities. In fact, some customers are so confident in the validity of our simulations that they've begun to make wholesale business decisions based solely on our results, with little experimental verification. With that much at stake we simply can't afford to make mistakes, and COMSOL is a valuable tool that we trust to deliver real-world accuracy." ❖

Justin McKennon, leader of the Modeling and Analytical Team, NTS.