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Baby, It's Cold Outside

Technologies exist that can melt ice on a wind-turbine blade or keep it from forming in the first place

By Dr. Rosemary Barnes

In the sleepy town of Lunderskov, Denmark, there's a 22-meter-long room that is climate controlled at minus-30 degrees Celsius. Dubbed the Ice Lab, it's a place where LM Wind Power engineers can study the effects of freezing weather conditions on wind-turbine blades and determine how best to mitigate them.

As wind energy gains prominence around the globe, major wind-turbine manufacturers are researching strategies that would allow their technologies to work in the coldest of climates. Because of their high winds and increased air density — not to mention their lower populations — colder regions are ideal for wind-energy production.

Challenges abound, though, and in 2002, the International Energy Agency (IEA) Wind Task 19 began gathering and coordinating recommended practices on cold-climate wind energy. One area on its radar is blade icing, a problem that has been tackled by a number of manufacturers in recent years. For when ice builds up, energy production goes down, and it can even come to a halt altogether.

MANY WAYS TO GET RID OF ICE

You'd think it would be easy to keep ice from building up on a wind-turbine blade. Try a little anti-freeze coating. Paint the blade black. Maybe try salting the blade like they do on icy roads. Unfortunately, none of these much-researched "easy" fixes has actually worked, according to the October 2012 edition of IEA Wind Task 19's State-of-the-Art of Wind Energy in Cold Climates.

Instead, many manufacturers have turned to electro-thermal heating, a conductive mat or mesh usually made of carbon fiber added to the blade's surface. The mat heats up when electricity is applied. These systems apply heat precisely to the ice layer, and they can be used in harsh environments.

Several other companies went a different direction, however, to a hot-air system — a technology many believe offers lower maintenance and greater reliability compared to electro-thermal heating.

Here's how the hot-air technology from LM Wind Power works: A heater fan unit is located at the root of the blade. Because all LM Wind Power blades are custom designed, the heater fan size can vary, depending on the blade size. An insulated duct sends the hot air through the blade's interior, all the way to the tip. Holes in the leading edge (LE) web direct hot air onto the blade shell. The holes are placed according to design needs, and flow and heat distribution can be tailored to local heat transfer conditions. The length of the de-icing zone varies, too, depending on requirements. Finally, the air returns through the LE cavity and an insulated return duct, the length of which is chosen based on the length of the desired ice mitigation zone and power requirements.

Compared to electro-thermal technologies, LM Wind Power's ice mitigation systems don't increase manufacturing cycle time. In addition, there's less chance of damage because all components are internal.

Finally, electro-thermal technologies are conductive, which can attract lightning and potentially damage the blades, and the warming technologies aren't extended to the blade tip for that reason. With a hot-air system, since no metal components are used beyond the blade root, there's no impact on lightning

protection, making it possible to remove ice very close to the tip.

DEVIL IN THE DETAILS

Numerous studies have shown that ice builds up at the LE and the tip more than in other areas, but these also are the most critical areas to aerodynamic performance. One challenge with hot-air technology: If the heater fan unit is at the root, the tip is the hardest area to reach, and the air can cool by the time it reaches there. The smaller internal area at the tip means that pressure losses are high by the time the air reaches there as well.

LM Wind Power was able to maintain a high air temperature by using an insulated supply duct. In addition, engineers increased the internal heat transfer coefficient by increasing the local velocity and turbulence of the air, using methods such as impingement holes to direct the hot air flow at the LE and other

ALSO IN THIS SECTION

procedures to increase turbulence locally. For a hot-air system that heats the inside of the blade, it is essential that the heat transfer through the blade shell matches the heat transfer from the blade to the air. The most efficient system will exceed this slightly to keep surface temperatures just above zero.

Additional design enhancements come with each customization. LM Wind Power works with its customers to design a blade for their particular turbine, and the company puts a lot of effort into determining where the hot air is most needed every time. Each turbine has different requirements, and the geometry of the blade can greatly affect air flow. Creating just the right design is critical to efficiency.

DESIGN DEVELOPMENTS CONTINUE

Many manufacturers begin their design research using analytical models. LM Wind Power's sophisticated flow model uses compressible flow equations to accurately model flow distribution, but turbulence and other local flow effects aren't captured with this model. A global heat-transfer model can estimate power requirements, while a local heat transfer model estimates local ice buildup potential and is used for structural calculations.

Another design method is computational fluid dynamics,

As wind energy gains prominence around the globe, major wind-turbine manufacturers are researching strategies that would allow their technologies to work in the coldest of climates. (Courtesy: LM Wind Power)

The goal of any ice mitigation system is to get the blade surface hot enough to either melt ice or prevent it from forming. (Courtesy: LM Wind Power)

The battle against ice on blades will continue as wind-energy markets expand into colder regions. (Courtesy: LM Wind Power)

or CFD, which basically splits a volume of space into sections to simplify a complicated 3D flow into a series of simpler flow analyses. For instance, CFD can be used to simulate external flow to determine heat-transfer requirements and internal flow steady state and transient analyses, to calculate surface temperature distributions, impingement from web holes, and internal heat transfer coefficient distribution. A number of these analyses might be used for a new blade design, depending on how novel the design or application is compared to previous designs.

ENTER THE ICE LAB

With its Ice Lab, LM Wind Power takes its research an additional step. Located 14 kilometers from the company's headquarters in Kolding, Denmark, the lab can be used to study the effects of cold climates on the most critical part of the blade — the tip. Instrumented with temperature, pressure, and sensor flows, the lab can provide data logging for transient analyses and is used to validate CFD and analytical models and to test new designs.

For most of LM Wind Power's new designs, the main focus is on maximizing heat transfer in the tip region. The goal of any ice mitigation system is to get the blade surface hot enough to either melt ice or prevent it from forming. The heat transfer requirements toward the root are generally much easier to achieve, so the company is concentrating on the tip.

With hot-air technology, it's hard to target specific areas, and LM Wind Power has focused on matching the flow and temperature distribution to local heat transfer requirements, she said.

LM Wind Power is also challenged by scaling effects, because as the blades get longer and slenderer, it is harder to get enough flow at a high enough temperature at the tip.

And there is another consideration:

Hot-air technology uses more energy than the electro-thermal technique, so it is important to optimize this as far as possible.

UPGRADING TO ANTI-ICING

The blade typically is stopped while de-icing takes place — up to several hours per blade — depending on conditions. Anti-icing technology, on the other hand, literally prevents the ice from building up in the first place, so the turbine continues to run. Since heavy icing sites can have ice accumulating up to 70 days per year, anti-icing technology has the potential for annual energy production gains at these locations.

With hot-air technology, researchers are using CFD analysis to determine the heat transfer required to keep the blade surface water in a liquid state. Compared to a de-icing blade, an anti-icing blade needs more insulation to maintain higher temperatures, an increased heat transfer coefficient at the tip, a higher flow rate overall, and an especially higher flow rate at the tip, which means a larger fan is needed to provide more flow and greater pressure gain.

UP TO THE CUSTOMER

The battle against ice on blades will continue as wind-energy markets expand into colder regions. When entering a new region, blade manufacturers need to work closely with customers, alongside meteorologists, to deepen their understanding of the weather conditions blades will face throughout their 20-year lifetime. Demand for systems to combat ice is growing, and the pressure to decrease the levelized cost of electricity (LCOE) from wind will drive ongoing improvements in the cost and efficiency of the technology.

To continue to compete in colder climates, research is key. So, as long as the winter winds blow outside, engineers will be found inside LM Wind Power's Ice Lab developing the next generation of de-icing and anti-icing technologies.

Dr. Rosemary Barnes is a senior engineer focused on de-icing at LM Wind Power. In 2016, she joined the Product Engineering and Blade Sub-Systems team at LM Wind Power's headquarters in Denmark. Previously, Barnes worked in her home country, Australia, as a design engineer and project manager in renewable energy and sustainability industries. She holds a Bachelor's Degree in Systems Engineering from The Australian National University in Canberra, and a Ph.D. in Composite Materials Structures from the University of New South Wales.

Chasing the Value

Innovation and industry maturity have brought additional options to gearbox repair and replacement.

By Brian Hastings

The total replacement cost for gearboxes needs to be reduced to make wind a more sustainable technology. (Courtesy: Shutterstock)

In any industry, value is often in the eye of the beholder. What works for one company may cost another significantly.

Five years ago, Gearbox Express (GBX) introduced Revolution for the Sle platform because a majority of those turbines were 5 to 8 years old. The theory was these assets would run 20-plus years in a market where power-price increases would be the norm and reliance on the Production Tax Credit (PTC) would phase out.

Fast forward to today and:

- Wind has become very competitive. According to Make Consulting, LCOE (levelized cost of electricity) is expected to fall below $35/MWh within the next five years, outstripping both coal and natural gas.
- Current development boom being fueled by the phase out of the PTC. PPAs (power purchase agreements) are coming in extremely low (sub $20/MWh in many circumstances). This underscores long-term importance of OPEX (operating expenses).
- Given low power prices, independent power producers in a post-PTC environment (after year 10) find it difficult to justify gearbox and or main-bearing replacement.
- Regulated utilities have a rate base used to justify upgrades and increased reliability. They continue to develop and expand wind largely as a long-term hedge against other forms of power generation while the PTC remains nice to have.
- A major "repower" wave is surging through the more than 8-year-old turbine market, exclusively driven by the PTC 80/20 rule. Over 7 GW is expected to undergo some sort of repower activity, qualifying for a second 10 years of PTC providing relief to OPEX pressures.

The total replacement cost for gearboxes needs to be reduced to make wind a more sustainable technology. Yes, power prices are likely to rise, but for wind to be sustainable long term, these costs have to be fundamentally lower while at the same time not sacrificing reliability. Owners of post-PTC turbines not repowering could be lured into chasing a low cost /used gearbox, only to quickly find out the value of its reliability is not there.

WHAT ARE THE OPTIONS?

Address the in-and-out cost.

- Traditional cranes are expensive. Wind is maturing, and newer technologies are now on the market that are cutting the in-and-out cost in half. Newer, self-hoisting systems can do the job for $75,000 to $100,000 while a traditional crane would cost $125,000 to $175,000. As acceptance in the industry increases, up-front capital cost will reduce, and the in-and-out cost could be as low at $50,000 to $75,000.
- Predictive maintenance is key. It is possible to use condition monitoring as a tool to manage time between failures with de-rating strategies. Turbines can produce power safely until it makes sense to perform the change-out, avoiding costly down time. Furthermore, economies of scale can be realized on the crane mobilization by lumping multiples together.
- Make smart investments. Certain

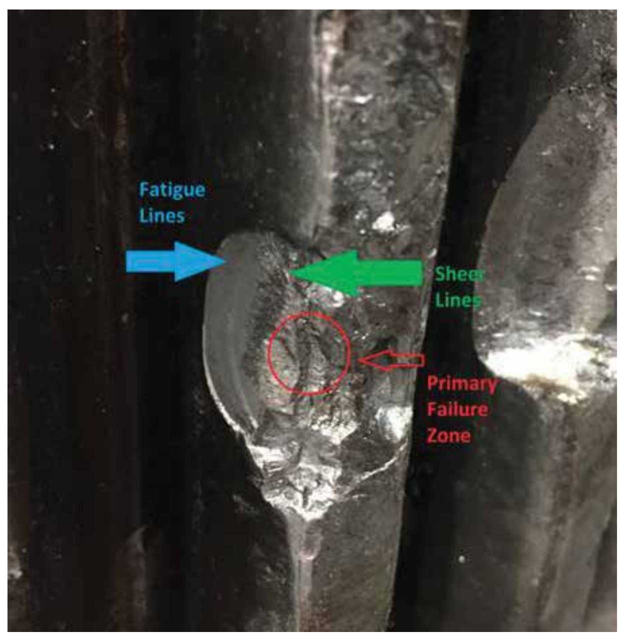
wear debris sensors have become cost effective. They now cost a third to half the price of a traditional full-blown vibration system.

Reduce the cost of the gearbox repair while understanding the reliability tradeoffs.

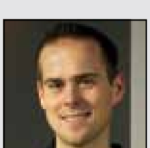
- A full set of replacement gearing represents approximately half the costs of a complete remanufacture. Re-using gears therefore presents a significant opportunity to save cost.
- Used gears can be successfully used if properly inspected to ensure within backlash tolerance and reground to 100 percent clean up (meaning it looks like a new gear). Using gearing as-is or without proper inspection is a recipe for disaster. This is the crux of the material aspect of any warranty: ensure the language is clear, as any gray area implies assumed risk. Make sure suppliers providing a guarantee are transparent with their specifications.
- It's reasonable to expect a properly reconditioned used gear will run another five to 10 years while a new gear would be expected to last 20 years. For example, if a turbine is 11 years old and the goal is to run beyond 20 years, additional investment must be made up-front so new material can be used. If the goal is only to run another nine years (to year 20), recertified gearing may be a better option. As an example, if the upfront purchase cost of a gearbox with all new gearing was $180,000, a gearbox using recertified used gearing could be $120,000.
- Bearings represent about a quarter to a third of the cost of a complete remanufacture. Paying 20 percent to 30 percent more for upgraded bearings in a few of the positions (planets, high speed, intermediate) will only marginally increase the cost of the gearbox (approximately 5 percent), but substantially improve reliability.
- The remaining cost of the gearbox relates to labor, lube system, seals, and a load test leaving little room for additional savings.

Value is often in the eye of the beholder. As an owner, value takes on different definitions over the life of the turbine. The good news is innovation and industry maturity has brought additional options, and more importantly, transparency, so all risks can be weighed and the true value found.

A Liftra Self-Hoisting Crane© in action. Newer, self-hoisting systems can do jobs for much less than a traditional crane. (Courtesy: Gearbox Express)



Material fatigue can cause serious wear, limiting the lifespan of a used gear vs. new. (Courtesy: Gearbox Express)



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