Picture 01 – Wind-farm Markbygden 1101 up-North Sweden deploying more than 1100 wind turbines

When the Greek god Aeolus meets the Norse goddess Skadi!

The growing demand for alternative energy has motivated countries to invest in renewable solutions, and although solar is getting a large amount of attention, in silence wind turbines are rapidly gaining market share. In less than 10 years wind turbines have become more efficient and more powerful, with the latest generation units being almost as high as the Eiffel Tower and able to deliver 13 megawatts of power - enough to supply energy to roughly 12,000 homes! To get the best out of their investment, wind farms operators are seeking the best locations where they have the highest ratio of wind per year. Northern latitudes and high altitude offer that mix.

Wind turbine challenges in cold climate conditions!
Exploiting the benefits of higher air densities in cold atmospheres and where there is less conflict with those objecting to wind turbines installations, wind farm operators are rapidly expanding their capacity in Northern regions.

One good example is the project Markbygden 1101 from the Swedish company Svevind, which started in October 2012 and will comprise of more than 1,000 wind turbines. Located West of Piteå, North of Sweden (65°24’59.99” N 20°39’59.99” E), the project will include 300 meters (984 feet) wind turbines. When completed the windfarm will generate up to a very useful 12 TWh per year (Picture 01).

Although the location may be ‘perfect’ in order to realize best performance, it is also very challenging to operate in winter conditions. Wherever you are on the globe, getting closer to the Artic Circle means exposure to freezing fog, snow, and ice formation, and this where the Greek god Aeolus meets the Norse goddess Skadi, often associated with winter.

Some energy analysts are considering that Northern and high-altitude windfarm operators could lose 35% of their revenue due to freezing conditions reducing their ability to operate wind turbines throughout all of the calendar year. We are used to seeing wind turbines in sunny places, and of course very few of those are aware of the challenges caused by icing when operating in cold conditions. The 2020-2021 freezing winter episode faced by the Chinese windfarm in Hunan that was completely frozen and unable to supply energy for several days caught media attention, exposing the Achilles heel of wind turbines in cold weather conditions.

For those of us living up North or in mountains areas, we are used to experiencing the power of icing and we are aware of the damage it can causes to infrastructures. Imagine what could happen to wind turbines operating in cold weather conditions when ice deposit on blades (Picture 02), rotors and measurement instruments?

Picture 02 – Frozen wind-turbine blade (Picture: PRBX / Courtesy of Nergica)

In the first instance, ice deposition will reduce wind turbine efficiency, and as the amount of ice increases cause severe problems and even fatal damage to the wind turbines and humans.

The icing process
By their concept and principle, wind turbines are exposed to tough atmospheric conditions, especially during the winter in Northern regions. In general, the different types of atmospheric icing that impact wind turbine development are in-cloud icing (rime ice or glaze) and precipitation icing (freezing rain or drizzle, wet snow). Understanding ice formation is important for wind turbine manufacturers when designing new equipment, especially those as high as the Eiffel Tower.

Rime ice:
Rime ice is formed from supercooled liquid water droplets contained in clouds or fog transported by wind. When the droplets hit a surface, they freeze immediately. If the droplets are small, soft rime is formed, but if the droplets are bigger, hard rime is formed. Rime ice growth is asymmetrical, located only on the windward side of a structure, and it can occur at temperatures down to -20 degrees C.

Glaze ice:
Glaze ice is caused by freezing rain forming a smooth, transparent, and homogenous ice layer, and has a strong adhesion to the structure. It usually occurs at temperatures between 0 and -6 degrees C, and has a higher density than rime ice. Freezing rain or freezing drizzle occurs when warm air melts the snow crystals and forms rain droplets, which then fall through a freezing air layer near the ground. Wet in-cloud icing occurs when the surface temperature is near 0 degrees C.

Wet snow:
Wet snow is partly composed of melted snow crystals with a high liquid water content. Its composition becomes sticky and able to adhere to the surface of an object. Wet snow accretion occurs between 0 and +3 degrees C.

As a result of climate changes, disruption is occurring in the Polar Vortex, resulting in unstable Northern cold waves meeting low pressure from the Atlantic Ocean. In such conditions, windfarms operating in Northern regions can face all three types of icing conditions within few days, resulting in a massive and devastating accumulation of mixed ice and snow.

The icing impact
Despite their apparent simplicity, wind turbines are complex machinery with each individual part supporting a specific functionality designed for high performance. As is the case with an airplane, the aerodynamics of the overall structure is critical regarding its ability to counter ice formation that would otherwise degrade performance. For example, when ice forms on the surface of the blades, it changes its mass and shape, causing unbalanced forces on the rotor and inducing vibration and oscillation thus affecting performance and possibly causing damage.

Ice formation on a wind turbine is not only a structural problem, it can also affect wind measurement and weather probes, leading to data loss and increased measurement uncertainty. Given the importance of such data, this is a major problem as it is needed to determine any measures needed to be taken in order to protect the installation and surroundings. Wind farm operators permanently monitor their installations and wind turbines are equipped with a number of systems that not only optimize performance but also prevent damage, which in case of the freezing of anemometers and other sensors can be very challenging.

There is also another aspect to the dangers of wind turbine ice aggregation to the operators in charge of maintenance. Ice can be catapulted long distances and even when simply falling from a tower it can seriously injure operators. So special procedures have been developed to protect operators when approaching and working on frozen installations.

Given that icing is a natural process, how can windfarm operators prevent it, and when impossible to do so, remove ice formation from wind turbines?

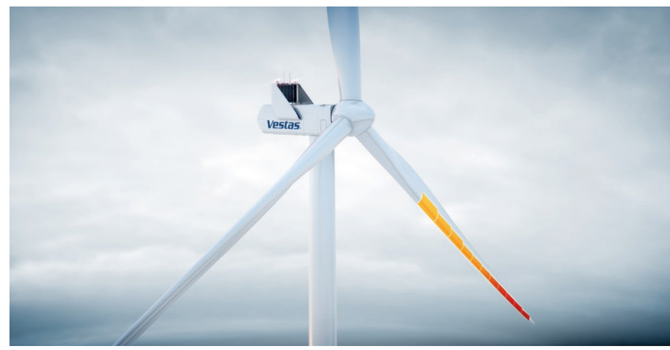
Prevention and de-icing
Many methods have been researched to monitor weather conditions and to make it possible for windfarm operators to take proper measures e.g., to cease operation before ice is able to damage blades and rotors, but most importantly to reduce the risk of ice sticking to blades. Depending on the construction and technology used by the manufacturer, different de-icing systems both passive and active have been developed and implemented in commercial products.

It is difficult to present all of them here, but we can summarize the most common techniques as being:

Passive anti-icing:
Because of their anti-icing properties, adding an ice-phobic coating layer to the edge of the blade will prevent ice from sticking to the surface. On a hydrophilic surface, water does not freeze in the areas where the surface temperature is kept higher than water freezing temperature. Another passive method is to use black paint that catches light radiation, allowing the blade to warm-up and help melt the ice layer. Black paint can also be used in conjunction with ice-phobic coatings.

Active anti-icing:

Heating elements: One of the most common techniques is to integrate heating elements into the edge of the blades. Manufacturers have developed advanced technologies combining carbon heating elements controlled by a local ice detector and connected to the wind tower SCADA (Picture 03). Usually installed during the manufacture of blades, some manufacturers offer upgrade kits to add de-icing systems onto existing wind turbines.



Picture 03 – Anti-icing heating elements, representation, on wind turbine blades– (Picture: PRBX / Courtesy of Vestas Wind Systems A/S)

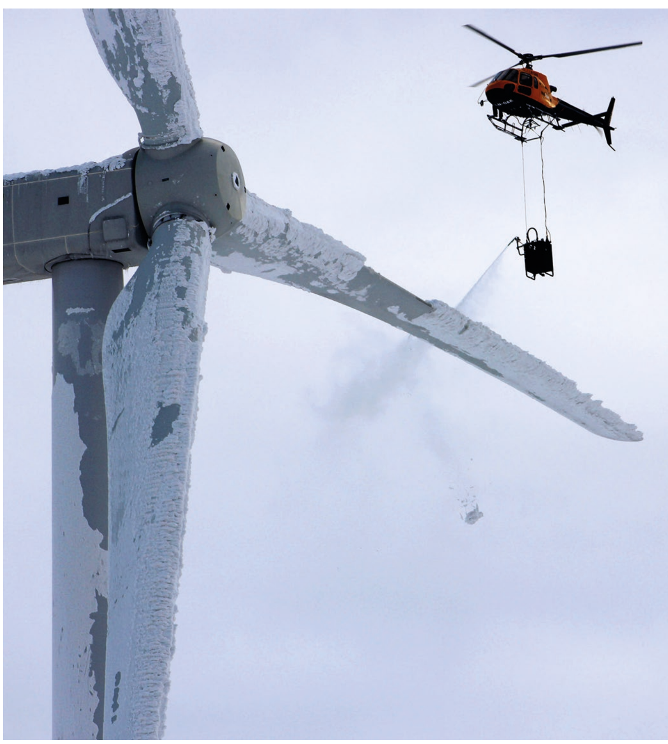
Hot air blade blower: A heater and blower are installed inside the blade. The air is pushed through a tube placed in the center of the blade, creating the hot air to circulate homogeneously and to warm the structure of the blade.

Hot air centralized blower: Instead of having individual heating system per blade, a central and more powerful heater is placed in the hub. Air is pushed inside the blades to warm them and prevent ice formation or to de-ice them.

Ice expulsion: Different techniques have been investigated to prevent ice forming and to expel ice when formed on the blades. Most of them are still at research level but it is interesting to mention:

- **De-ice Boots:** As on some airplanes, a pneumatic system is placed on the edge of the blades. By applying a cycle of blowing and inflation the ice is cracked and expelled.
- **Ultrasonic waves:** This technique uses the generation of ultrasonic waves, inducing vibration to avoid ice-formation or to weaken ice formation by creating micro-cracks, facilitating ice removal.
- **Microwaves:** Originally developed for aircraft use (e.g., US patent US 6,207,940 B1) this technology is based on microwaves being generated by a gyrotron and guided to the radiated surface coated with a film inserted with carbon nano particles, absorbing microwaves and creating heat.

Airborne de-icing: In certain conditions, the only way to remove accumulated ice is, as it is for an airplane prior to takeoff in icy conditions, to spray a de-freezing solution on to the blade. In the case of wind turbines, it is not possible to spray from ground level and airborne spraying is the only way. For environmental reasons it is not possible to use de-freezing chemicals, and so hot water is used. For many years this technique has been used ad-hoc, and it's only since 2016 after the Swedish organization 'Energiforsk' ran an extensive project that a way of working and best practice was established. And so today, with the evolution of commercial drones, many companies are using them for de-icing (Picture 04).



Picture 04: Airborne de-icing by helicopter projecting hot-water on the frosted blades (Picture: PRBX / Courtesy of Energiforsk)

In conclusion:
Wind turbines are getting taller, gaining in efficiency and gaining in power. However, when the Greek god Aeolus meets the Norse goddess Skadi, even amazing technology can freeze on its feet. Predicting icing conditions, preventing the formation of icing and when it sometimes unavoidably does form, to safely clean and remove it is an interesting area for engineers to develop further. We should consider new power technologies such as harvesting energy, which could contribute to power micro de-icing cells. In truth, although a lot of things have been done already, we are still only in the early stages and we can expect a lot of technological innovations to come.

Europe has a plan to become the first climate neutral continent by 2050 and keeping Nordic windfarms in operation when Aeolus meets Skadi is a must and a challenge that engineering and electronics engineers are actively working on.

Note:
This paper was presented first, May 2021, in the magazine Power Systems Design (PSD) EU/US/China.
https://www.powersystemsdesign.com/

References:
Svevind AB Markbygden 1101: https://svevind.se/en/13290-2/
Nergica: https://nergica.com/en/wind-power/
Vestas: https://www.vestas.com/
Energiforsk: https://energiforsk.se/program/vindforsk/rapporter/airborne-de-icing-solutions-for-wind-turbines-2016-300/
Powerbox: https://www.prbx.com/

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