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Design Procedures and Experimental Verification of an Electro-Thermal De-Icing System for Wind Turbines

By David Getz and Jose Palacios

The paper reports the design process of a de-icing system for HAWTs, based on an experimental analysis of an iced rotating DU 93-W-210 airfoil. At first, ice is accreted on the rotating model. Then the model is set to rotate at a precise speed, chosen to match the centrifugal force of a full-size blade at a certain radial position. The electro-thermal de-icing system is turned on, and, if the accreted ice is thicker than a certain threshold, the ice sheds due to centrifugal force within the maximum fixed time of 30 seconds.
This procedure is repeated for different radial positions. The minimum thickness required for ice shedding is determined and, at last, an effective time sequence is developed to shed portions of ice consecutively, from the tip to the inner part of the blade.

The English language is satisfactory. The topic is of sure interest for the WES reader.
The article seems to be a summary of much longer text(s) and, as such, contains some non-essential information as well as unnecessary repetitions. In some parts it also contains contradictory information. **Re-writing from scratch is advisable**.

The Reviewer has some major concerns about the experimental ice accretion procedure and its relationship with a real wind turbine, as follows:

The representative 1.5MW wind turbine used as reference is too generic, and no information is provided about it, except for the supposed length of the blade (reported only in Figure 9). The rotational speed, which is used both for ice accretion experiments and to calculate the centrifugal force on the blade, should be provided explicitly (since it is a fundamental datum for the experiments), but can only be retrieved by putting together information from Table 1 and Figure 9. The resulting rotational speed should be 18rpm.

The icing experiment is done on a single, scaled airfoil, but no information about scaling is provided within the article. In fact, scaling methods seem to be completely ignored. Reference [1] , included in the submission as Reference [32], is an entire Master Thesis about scaling methods developed at the very same AERTS Laboratory. In [2] the same author of [1] applies a scaling method to study a wind turbine blade at AERTS Laboratory.

RPM is said to be matching "the impact velocity at a chosen span percentage of a wind turbine" (Line 226-227), but no information is provided about the free-stream velocity; inflow parameters seem to be neglected as well. Again, see [2] as reference.
The authors also neglect the effect of chord and cross section (both of which vary along a blade span) on the collection efficiency of the airfoil (see, for instance, [3]).

As a result, ice thickness is found to increase linearly with rotor span, "as expected" (line 236). The authors also feel confident to extrapolate the data trend outside the tested range (line 238). The result is surely valid for the experiment done and, more in general, the relation seems to be valid for a straight, untwisted, untapered (and non-lifting) blade, but is not valid for an actual wind turbine blade in power production. Some numerical results of ice accretion on a full blade can be found, for instance, in [4]. If this is a choice, in seek for simplicity, it should be pointed out.

Due to this lack of specificity, the time sequence found is strictly related to the experiment and provides qualitative data only. The design process is still valid. Again, if this is a choice, it should be pointed out.

Moreover, contradictory information is provided: lines 116-117 state "Representative icing conditions were selected and guided by FAR Appendix C icing conditions typical of aircraft environments", while lines 155-156 state "The density value was selected as it is representative of that seeing on wind turbines". In general, is not clear how these conditions were chosen.

In view of all this, the authors should (a) comment the choices made for ice accretion tests, by pointing out the reasons leading to these choices and the limits of validity of both the accretion test and the following results, or (b) repeat the experiment in more realistic conditions. In both cases the relationship with the considered wind turbine should be made clear and the set of boundary conditions should be justified properly.

[1] Han, Theoretical and Experimental Study of Scaling Methods for Rotor Blade Ice Accretion Testing," The Pennsylvania State University, 2011.
[2] Han et al., Scaled ice accretion experiments on a rotating wind turbine blade, J. Wind Eng. Ind. Aerodyn. 109 (2012) 55–67
[3] Homola et al., The relationship between chord length and rime icing on wind turbines, Wind Energ. 2010; 13:627–632
[4] Yirtici et al., Ice Accretion Prediction on Wind Turbines and Consequent Power Losses, J. Phys.: Conf. Ser. 753 (2016) 022022

Minor concerns are as follows:

- The authors state that the time sequence is designed to "minimize aerodynamic penalties" (line 377). In order to minimize aerodynamic penalties, ice at blade tip (zone 1 and, at most, zone 2) should be shed as soon as possible. Moreover, figures 27-29 can be difficult to read. Maybe a dashed line for the "minimum" line and a solid line for the others could be a better solution.

- the abstract is too long, detailed, redundant and confusing. It is advisable to make it shorter for better clarity.
  It also contains misleading information or information missing in the article, such as:

  - "Wind turbine representative **airfoils** […] were tested" (one single airfoil is tested);

  - "**The wind turbine sections were ½ scale models of the 80% span region of a generic 1.5 MW wind turbine blade.** A sample wind turbine configuration was selected to describe the design process. A 1.5 MW wind turbine was chosen". (Bold: information missing in the article. The rest is included to show the lack of consequentiality within the information provided by the abstract).

- some statements should require a reference, in particular:
  - Lines 83-85: "Typically, the LWC and MVD affect the thickness of the ice shape, while temperature and droplet impact velocity affect the surface roughness and adhesion strength of the ice."
  - Lines 92-93: "In general, the evaporative mode for anti-icing systems require about 5 times more energy to operate, rendering it as too expensive for wind turbines."
- There are a few errors to be corrected, as listed below:
  - Line 151: "Figure 6: Wind Turbine test blade representative (**Han, 2015**)".
  - Line 259 & Line 270: Table 2 & Table 3 should be corrected. Heater #, Span %, and data are mixed. Table 4 (line 348), on the contrary, is fine.
  - Lines 308-310: data provided are reversed. It should be "the minimum ice thicknesses were **6.8 mm** [text: 3.7 mm], 5 mm and **3.7 mm** [text: 6.8 mm], respectively." The same goes with all the data provided up to line 310.
  - Lines 458-467 the order of the References is wrong.

Other comments:

- Lines 62-63: "It is estimated that the capacity will reach 425 GW by 2015". This is meaningless in 2020. More in general, lines 55-69 give no added value to the article and could be omitted.
- The LEWICE study, which is cited but not presented, could be briefly introduced for completeness.
- More in general, if re-written, the article could contain more information in the same space, or the same information in less space, being shorter and clearer at the same time, and removing unnecessary repetitions and contradictions.

In view of the above comments, the Reviewer suggests that the paper undergoes a major revision, before being re-considered for publication on Wind Energy Science.