Dear Reviewer,

Thank you for taking time to review our article. With your suggestions you have provided valuable insight on how to improve the paper. As suggested, we have added more validation test cases for both ice accretion and roughness. We have also made the paper clearer by adding significant images and tables.

You can find our answers below each of your comments. In *italic blue*, you can also find how we addressed the comment within the manuscript. The references included in our answers can be found in the revised manuscript.

Regards,

The Authors

Anonymous Referee #2

This paper investigated the effects of roughness on airfoil performances under ice conditions. In this paper, NERL 5MW model was applied to perform numerical simulations. To analyse the power performance of the iced blade, DLC1.1 was considered with two different roughness cases, W_std and S_std. Detailed comments are addressed below.

Comments

Reviewer Comment

IEA task 19 published a report about available technologies for wind energy in cold climates where detailed IPS cases were reported. This report should be reviewed

Authors Response

Thank you for your suggestion. We have reviewed the report. We focused on ice accretion models rather than IPS, the former being more in line with our paper.

We have updated the text and included a review of the report in the Introduction (ll. 34-45).

Reviewer Comment

Recently, there were studies to investigate surface roughness effects for simulating ice accretion. These papers should be reviewed.

(https://arc.aiaa.org/doi/10.2514/1.J060641, https://arc.aiaa.org/doi/10.2514/1.J059222)

Authors Response

Thank you for your suggestion. The first paper deals with boundary conditions in roughness-induced transition with no explicit relation with ice accretion simulations. The second paper includes a roughness-induced transition in ice accretion simulation, showing that transition is important for glaze ice shapes (as it affects heat transfer), while it is negligible for rime ice simulation. We have included the latter in the methodology to support neglecting transition in rime ice simulations. Feindt's experiment on the roughened flat plate (Feindt, 1957), which is used for validation in both papers, was used to explain why using fully-turbulent flows provides an acceptable approximation when computing aerodynamic coefficients of iced airfoils.

The papers were reviewed at the end of Section 2.2 (ll. 270-287).

Reviewer Comment

In section 2.4 the authors introduced the extended roughness area: 25%, 18%, 15%, 13%, and 11% along the blade span shown in Fig. 3, respectively. I think it is one of the most important parts of this paper. But there is no detailed description of how these values were introduced. It must be clearly described.

Authors Response

The extended roughness region is 0.44m and is constant among all sections, so its non-dimensional

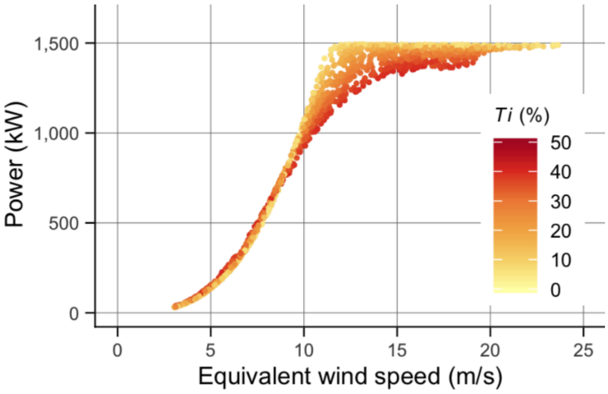
value (non-dimensionalized with respect to the chord of the section) reduces from tip to root. At the tip, the value is 25%. At mid-span, the value is 11%. The value of 25% at the tip was chosen to match the one imposed by Etemaddar et al. (2014) on all sections. In this study, it was chosen not to keep this value constant in non-dimensional value, since it would be physically wrong. Larger sections generate higher pressure gradients, which deviate more the droplets. So, they collect fewer water droplets as compared the smaller sections at the tip. For this reason, the rough region should be higher at the tip and diminishing going towards the root.
We have clearly explained this concept within the text (ll. 349-369). For clarity, Figure 4 representing the "std" and "ext" regions was also included, as well as Table 3 with a test matrix.

Reviewer Comment
In Figs. 11 and 12 two different comparison studies were presented. It was shown that the current numerical results were not able to accurately predict the ice shape compared to the experimental test results. The author mentioned that "the ice impingement limit on the lower surface was underestimated". It might be due to that impinged water does not freeze at the surface and exists as a water film. Therefore, it might be good to check the heat transfer rate.
Authors Response
The ice shape on the leading edge was actually captured fairly well with the proposed methodology. We updated the figure by increasing the sampling rate on the experimental data. The test case is fully rime and there is no runback water (there are both a low freestream temperature and a very low LWC). The most likely reason for the underestimation of the impingement limit with respect to the experiments (which is common to any numerical ice accretion engine) is that a cloud is made by a distribution of droplet diameters and the MVD is just an indicator of the median of this distribution. Parcels with higher diameter have a higher mass, and their trajectory is less deflected by the pressure gradient. Thus, a wider portion of the airfoil gets wet. This issue may be overcome with a multi-bin approach, i.e., by performing the weighted average of the collection efficiency computed with different droplet diameters from the distribution. However, this wouldn't affect significantly the results and the conclusions presented, and the multi-bin approach goes beyond the scope of this work.
To prove that our results are consistent with experiments and other ice accretion engines, the six remaining AERTS test cases for rime ice were included, i.e., #4, #15, #16, #17, #18, and #19. For these test cases, a LEWICE solution is available as well. The results obtained with the proposed multi-step ice accretion setup agreed well both with the experiments and also with those provided by Han et al. (2012) for LEWICE. Both PoliDrop-PoliMIce and LEWICE showed the same behaviour in terms of impingement limits, and the reason is the one described above.
Section 3.2 was updated to include the six new validation test cases. Results are shown in Figure 13. The underestimation of the impingement limits on the lower surface was also explained (ll. 408-432).

Reviewer Comment
In Fig. 13, how do the authors ensure the predicted ice shapes are correct? Moreover, the ice shape at the blade tip areas (section A-C) seems very irregular horn shapes. Is it obtained under the rime ice condition? In general, more validation studies are required to prove the current numerical model's accuracy.
Authors Response
More validation cases have been added to ensure that the ice shapes are correct. The ice shapes on all sections (A-E) are rime ice. The irregularities on Sections A-C come from some small oscillations on the collection efficiency, which eventually get amplified. This happens because geometries are not being smoothed during grid generation, unless strictly required. Since real ice shapes are highly irregular, this was considered acceptable.
More validation test cases have been added (Figure 13). We have also specified that the geometry is not subject to smoothing, unless strictly required for grid generation purposes (ll.304-305; 442-434).

Reviewer Comment
On page 20, section 4.3, why is after the optimum TSR value interested?
Authors Response
High TSR values are used by this wind turbine in Region 1.5, i.e., from the cut-in wind speed (3 m/s) up to approx. 8 m/s. In this velocity range, the TSR decreases from 15.3 to its optimum value.
We have added this information in the text by specifying what is the Region 1.5 (ll. 506-507).

Reviewer Comment
Figure 23 shows the power curve under turbulent wind conditions. Why clean airfoil case where no ice is accumulated could not obtain the rated power, 5MW, at the rated wind speed? Since there is no ice accumulated with the clean airfoil model, it should produce the rated power at the rated wind speed.
Authors Response
The rated power is produced at the rated speed with a steady wind, i.e., when the turbulence intensity (T.I.) is zero. As the T.I. increases, the 10-minute averaged power reaches the rated power at higher wind speeds. This information can be found for instance in https://doi.org/10.1088/1742-6596/524/1/012109 from which picture below was taken.



The concept can be shown with some reasoning. Let us consider a simplified example. Given an average wind speed of 13 m/s, which is above rated speed, the instantaneous one will be, e.g., 13 m/s ± 4 m/s. At instantaneous wind speed above rated one, the wind turbine will produce approximately the rated power. At instantaneous wind speed below the rated one, the wind turbine will produce a below-rated power. Thus, the average power will be necessarily below the nominal rated power. For similar reasoning, before the "inflection point", the power produced is slightly higher than the 0 T.I. case.
We have specified the effects of turbulence intensity in the text (ll. 518-520). For completeness, we have clearly specified the reference T.I. prescribed by DLC 1.1 for the wind turbine under analysis (l. 184).

Reviewer Comment
Overall, this paper needs more validation studies to prove that the current model is valid for 3D wind turbine rotor simulations. Furthermore, roughness model validations are required.
Authors Response
A classic quasi-3D BEM approach was used for icing. It is known that the model is valid for 3D simulations, in the sense that it is possible to approximate 3D ice accretion simulations with 2D sections (Switchenko et al., 2014). The validation of our numerical setup for ice accretion has now been expanded including new test cases.
The validation of the roughness model was already shown in Section 3.1 by comparing the law of the wall on a rough airfoil with the theoretical velocity profile. Since we considered only $k_s/c = 0.0005$, we have included the results of another simulation with $k_s/c = 0.005$. The figure has been modified so that in the first row there are the results of $k_s/c = 0.0005$ on the upper surface of the airfoil, while in the second row there are the results of $k_s/c = 0.005$ on the lower surface of the airfoil. The results of the law of the wall on a smooth airfoil were also presented and compared with the theoretical velocity

profile.

We have updated Section 3.1 by adding another value of $k_s/c = 0.005$ *for the validation of the roughness model. (ll. 392-401 and Figure 11).*

Reviewer Comment

Many studies have already investigated the power performance of a wind turbine with and without ice accumulations. Therefore, there is no novelty in evaluating the power performance with a CFD tool. One of the most exciting parts of this paper is considering the surface roughness effects. However, it is not clear how different surface roughness was considered and implemented into the simulations.

Authors Response

We have updated the description of how the different roughness cases were chosen, as specified in a previous answer. We have also slightly expanded the description of the law of the wall, including the smooth regime. The description of the roughness-modified Spalart Allmaras turbulence model and its numerical implementation in SU2 is available in the work by Ravishankara et al (2020). The turbulence model itself is presented in the work by Aupoix and Spalart (2003). Presenting this turbulence model and its numerical implementation is out of the scope of this paper.

We have included the description of the law of the wall in the smooth regime (ll. 210-214). The reference (Aupoix and Spalart, 2003) was missing and has been added in the text (ll. 252, 573-574.)

Reviewer Comment

Based on the aforementioned comments, this reviewer recommends rejecting this paper.