Probabilistic fatigue analysis of small wind turbine blade using aeroelastic analysis
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Abstract
For fatigue load design of small wind turbines, IEC61400-2 Ed.2[1] provides two fatigue load calculation methods: Simplified load model(SLM) and aeroelastic modeling. Although aeroelastic modeling includes more realistic effect, most of small wind turbines below 1kW in Japan are designed using SLM because of the complicated procedure of aeroelastic modeling. So, we aims to reveal how SLM is applicable for these “micro wind turbines” and how these turbines designed for SLM are safety or danger sized or how much the cost of energy increase or decrease using SLM instead of aeroelastic model. Moreover, we wish to establish more practical and theoretical load design method affordable for micro wind turbine manufacturers.
In this research, fatigue load design is focused. Fatigue load estimation by the aeroelastic modeling was carried out for AURA1000 135W small wind turbine with 1m diameter. In this research, the results were compared with the simplified load model (SLM). And the reasons of difference between two methods are discussed.

An aeroelastic simulation code for 5 bladed wind turbines based on NREL's FAST[2] is used for aeroelastic modeling. Four annual wind speed distributions are considered; Class I to Class IV defined in IEC614000-2 Ed.2.
The result of fatigue load showed that SLM is more sensitive to annual average wind speed than the aeroelastic modeling. And the difference indicated that SLM’s assumption cannot be applied for the researched turbine.

In addition, the idea of representative operational range around Vdesign which is used in SLM is applied for the result of Aeroelastic model. It is revealed that wider range than the assumption of SLM in most cases. Especially in Class IV, the ranges were unrealistic value.

Results and Discussion

1. Lifetime Damage Equivalent Load
All results are compared by means of Blade root flapwise 1Hz Damage Equivalent Fatigue Load.

Fig.2 shows lifetime damage equivalent fatigue load normalized by ultimate strength. Judging from the figure, SLM is more sensitive to wind speed. At Class IV SLM shows almost 60% lower load that correspond to 10000 times longer life.

2. Load level at Each Wind Speed Bin
Short term fatigue load at each bin is shown in Fig.3. Fatigue load from aeroelastic model decreases over 11m/s due to the brake.
This figure reveals that the assumption of simplified load model is different from the actual state in aeroelastic model view of short term fatigue load. One possible reason is that the assumption of SLM is not the representative condition of the condition simulated by aeroelastic model around each wind speed bin.

3. Weight of Wind Speed Bin in Aeroelastic Modeling
Fig.3 shows how each wind speed bin contributes to the total fatigue cycles(20years: 630720000times). Judging from Fig.7, Wind speed region around 10m/s is dominant for DEL in spite of the different annual average wind speed for each turbine class.
On the contrary, SLM assumes the wind condition only around Vdesign. Because Vdesign becomes lower as class number increases, the consideration of critical wind speed may not be sufficient with SLM.

4. Representative Rotational Speed Range of Aeroelastic Model
For further understanding, a single representative rotational speed range (±0.5% of design speed) in SLM for the fatigue load from aeroelastic modeling (Fig.2) is shown in Table 2.

Table 2: Representative Rotational Speed Range

<table>
<thead>
<tr>
<th>Turbine Class</th>
<th>V_ave (m/s)</th>
<th>Vmax (% of design)</th>
<th>Vmin (% of design)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>10.6</td>
<td>0.045</td>
<td>0.032</td>
</tr>
<tr>
<td>Class II</td>
<td>10.9</td>
<td>0.057</td>
<td>0.043</td>
</tr>
<tr>
<td>Class III</td>
<td>10.9</td>
<td>0.074</td>
<td>0.061</td>
</tr>
<tr>
<td>Class IV</td>
<td>10.5</td>
<td>0.138</td>
<td>0.105</td>
</tr>
</tbody>
</table>

Conclusions
- The fatigue load from aeroelastic modeling is less sensitive than Vave than SLM.
- SLM is more sensitive to wind speed distribution than aeroelastic modeling. The difference is not considered in SLM. Second, the assumed operational speed at each wind speed bin in aeroelastic model was different from the assumption of Vave of Wind turbine, due to turbulence, control etc.
- The idea of representative rotational speed range for the result from aeroelastic modeling showed wider range than the assumption of SLM. Especially in Class IV, the ranges were unrealistic value.

With such differences in fatigue load, simplified load model provides larger margin in ultimate load than aeroelastic model which assures sufficient fatigue life for the target turbine. Therefore, the design of the target turbine has no practical fault. So, further in-vestigation including ultimate load is needed for more theoretical and cost effective load design of wind turbine in addition to the fatigue load discussed in this study.

References

EWEA 2014, Barcelona, Spain: Europe’s Premier Wind Energy Event