IDENTIFICATION OF VARIATIONS OF ANGLE OF ATTACK AND LIFT COEFFICIENT FOR A LARGE HORIZONTAL-AXIS WIND TURBINE

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Abstract The current paper investigates the effects of various elements including turbulence, wind shear, yawed inflow, tower shadow, gravity, mass and aerodynamic imbalances on variations of angle of attack and lift coefficient for a large horizontal-axis wind turbine. It will identify the individual and the aggregate effect of elements on variations of mean value and standard deviation of the angle of attack and lift coefficient in order to distinguish the major contributing factors. The results of the current study is of paramount importance in the design of active load control systems for wind turbine.

INTRODUCTION

Atmospheric boundary layer imposes several important operating conditions on wind turbine blades, i.e. unsteady variations of wind speed and direction with gradients of mean speed in both vertical and lateral planes. These characteristics stem from atmospheric turbulence, wind shear and yawed operation of wind turbines. These elements together with gravity and imbalances (mass and aerodynamic) are of paramount importance for wind turbines as they result in unsteady loads on the blades. Unsteady loading can lead to structural resonance and fatigue damage and finally structural failure. The unsteady loads are caused by variations in angle of attack (α) and force and moment coefficients correspondingly. Therefore, identification of the variations of α and lift coefficient (C_L) under various loading conditions are of great importance for wind turbine blades. Identification of the major contributors to unsteadiness on wind turbine blades can be the guideline for active load control mechanisms.

METHODOLOGY

In order to identify the effects of unsteady loading sources on fluctuations of α and C_L, a series of aeroelastic simulation cases were carried out using DTU's dedicated wind turbine aeroelastic software *HAWC2* '*www.hawc2.dk*'.
Each simulation case covered $4 - 24m/s$ with steps of $2m/s$, with a duration of $1100s$ and time step of $0.02s$. The last $600s$ are the data capturing period according to $IEC - 61400 - 1$ standard [3].
The simulations were done using DTU reference wind turbine *DTU-10MW-RWT* structural model and controller[1] which is a 3-bladed upwind pitch-regulated yaw-controlled HAWT.
The wind model applied used a '*Power law*' with exponential of 0.2 for wind shear according to [3], the *Mann* turbulence model to generate turbulent inflow and the potential flow model for the tower shadow effet.
The aerodynamic model was the BEM model implemented into *HAWC2*. It accounted for tip loss correction, induction correction by Glauret method, yawed inflow wind, dynamic stall correction by MMH Beddoes method (a modified BeddoesâĂŞLeishman dynamic stall model [2] for wind turbines) and aerodynamic drag for the tower and nacelle.

RESULTS AND DISCUSSION

The study focused on investigation of the variations of α and C_L for various unsteady loading cases where the 'Clean' case has only gravity and imbalances as the sources of unsteady loading but no tower shadow, wind shear, yaw and turbulence and the other cases are compared to correspondingly to identify the effects.
The results showed that almost all the unsteady load sources reduce the mean value of α and C_L along the blade. The reduction is to a greater amount from midspan to tip while small to negligible reduction is seen near the root.
The case is totally different for the fluctuations of α and C_L where all the unsteady loading sources increase the fluctuations of α to various amounts. The values are normalized with the relevant values for the 'Clean' case to make the increments more self-explaining. The most important understandings from these result are described below:

- Tower shadow has a negligible effect on the fluctuations.
- Yaw increases the fluctuations by a factor of 2 almost uniformly along the span.
- Wind shear increases the fluctuations by a factor of 2 near the root. This factor increases almost linearly to 4 for $\frac{r}{R} = 0.3 - 0.7$ and stays constant outwards to tip.
- Turbulence ($TI = 16\%$) will result in a huge increase in fluctuations. The level of increase starts from a factor of 12 near the root, increases to a factor of 14 around the midspan (where the mean values are the lowest) and decreases

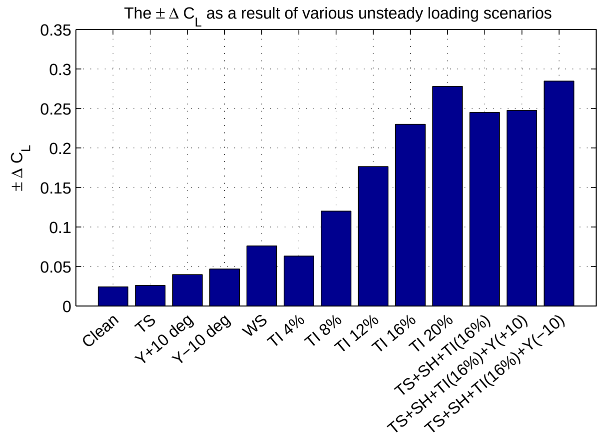

Figure 1. Influence of unsteady loads on averaged ΔC_L.

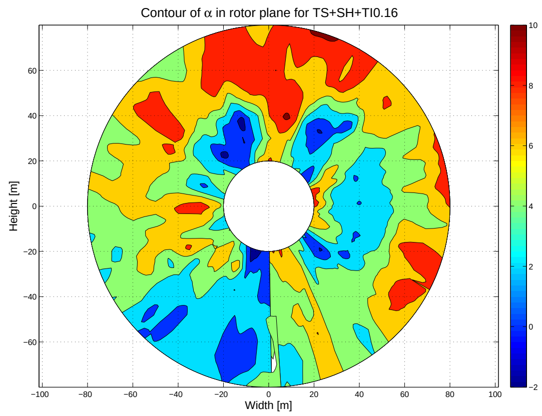

Figure 2. Contour of α over rotor plane under the effect of turbulence, wind shear, tower shadow, gravity, mass and aerodynamic imbalances.

to a factor of 10 when it reaches the blade tip.

A graphical comparison of the effect of various unsteady loading scenarios on ΔC_L is shown in Figure 1. The value of ΔC_L is averaged over the entire blade for each case. The figure shows that an average value of $\Delta C_L = \pm 0.25$ can be a typical value for a Class-A horizontal-axis wind turbine.

This finding is of paramount importance as it can be used to figure out to what extent the active load control mechanisms are capable of mitigating the fluctuations of C_L.

Variations of α for a single rotation of the blades are plotted over the rotor plane (shown in Figure 2) for the reference case, which is a representative of a real operating case for a wind turbine Class-A.

It is observed that the wind shear results in higher α in the upper half plane, however, the presence of eddies of various sizes are observed which result in regions of low and high α in various parts of the plane.

Therefore, turbulence as the main reason for large ΔC_L over the entire blade and the main source of unsteady loads results in local unsteadinesses. Thus, any load control system targeted for maximum mitigation should act locally and distributed radially on the blade. It shows that the distributed flow control methods can be the best solution for load control on wind turbine blades rather than whole-blade load control methods like individual pitch control (IPC).

CONCLUSION

The main findings of the current research are:

- The fluctuations of α and C_L are almost uniform along the blade with slightly higher variations near the root.
- The presence of turbulence, wind shear, yaw and tower shadow decrease the mean value of α and C_L along the blade. The reduction is negligible near the root.
- Turbulence dramatically increases the fluctuations in α and C_L. For Class-A wind turbine with reference turbulence intensity of 0.16, fluctuations are $10 - 14$ times compared to the case with no turbulence.
- Wind shear and yaw increase the fluctuations of α and C_L for $2 - 4$ times and 2 times respectively. Tower shadow has a negligible effect.
- For a Class-A wind turbine, fluctuations of C_L are in the range of $\Delta C_L = \pm 0.25$. This is an important guideline for the design of active load control mechanisms for wind turbines.
- Fluctuations are mainly local due to turbulent eddies and any active load control system acting locally can achieve higher mitigation.

References

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