Identification of variations of angle of attack and lift coefficient for a large horizontal-axis wind turbine

Citation for published version (APA):

Document license:
CC BY

Document status and date:
Published: 01/01/2015

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:
• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher’s website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:
www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:
openaccess@tue.nl
providing details and we will investigate your claim.
IDENTIFICATION OF VARIATIONS OF ANGLE OF ATTACK AND LIFT COEFFICIENT FOR A LARGE HORIZONTAL-AXIS WIND TURBINE

Abdolrahim Rezaeiha\textsuperscript{1,2}, Maziar Arjomandi \textsuperscript{3}, Marios Kotsonis \textsuperscript{1} & Martin O.L. Hansen \textsuperscript{2}

\textsuperscript{1}Faculty of Aerospace Engineering, TU Delft, Netherlands
\textsuperscript{2}DTU Wind Energy, Denmark
\textsuperscript{3}Dept. of Mechanical Engineering, University of Adelaide, Australia

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 \((\alpha)\) and force and moment coefficients correspondingly. Therefore, identification of the variations of \(\alpha\) 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 \(\alpha\) 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 \(4 \rightarrow 24\) \(m/s\) with steps of \(2\) \(m/s\), with a duration of \(1100\) \(s\) and time step of \(0.02\) \(s\). The last \(600\) \(s\) are the data capturing period according to IEC – 61400 – 1 standard \([2]\). 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 effect.

The aerodynamic model was the BEM model implemented into HAWC2. It accounted for tip loss correction, induction correction by Glauert method, yawed inflow wind, dynamic stall correction by MMH Beddoes method (a modified BeddoesŠLeishman 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 \(\alpha\) 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 \(\alpha\) 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 \(\alpha\) and \(C_L\) where all the unsteady loading sources increase the fluctuations of \(\alpha\) 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 \(\frac{L}{R} = 0.3 - 0.7\) 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...
A graphical comparison of the effect of various unsteady loading scenarios on $\Delta C_L$ is shown in Figure 1. The value of $\Delta C_L$ 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 $C_L$.

**CONCLUSION**

The main findings of the current research are:

- The fluctuations of $\alpha$ 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 $\alpha$ and $C_L$ along the blade. The reduction is negligible near the root.
- Turbulence dramatically increases the fluctuations in $\alpha$ 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 $\alpha$ 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**

