

Wind Farm

NIELS VAN DUIJN, JURRIAAN GOVERS, LUUK VAN HAGEN
JOCHEM HOORNEMAN, MAX VAN LEEUWEN

TU Delft
j.a.govers@gmail.com

May 24, 2017

Abstract

*This will be the abstract of our paper. We will show how cool our research is and how important we are.
Blabla Lorem ipsum.*

I. INTRODUCTION

TO minimize cost of wind energy and to efficiently use resource rich locations, wind farms are constructed, characterized by a large concentration of wind turbines. An inherent side effect of wind turbine however is a wake. When wind turbines are placed in close proximity of each other in a wind farm, a wake can have negative effects. A wake forms behind an upwind wind turbine and can have severe effects on the power production and loads of the downwind turbine.

With an increasing role of wind energy in Europe's energy production (nationale energieverkenning) it is important for wind farms to be able to meet the demands of the power grid (Tande). Controlling the power output of a wind farm is essential because an overload of energy can decrease the stability of the power system (Tande). Currently, most wind farms operate based on 'greedy control', meaning that the individual turbines always try to deliver maximum power. This causes a problem when the power demand is low and the dependency on the wind energy is high, resulting in an overload of the power system. Active power control can solve this problem, by regulating the power output of a wind farm.

Misschien ergens nog iets over een wake?
Over wind farms algemeen?

There are several methods of active power control in a wind farm, two of which will be discussed in this paper, that is, yaw control and axial induction control. Yaw control can be used as a method to reduce the power output of a single wind turbine and as a method to increase power output of a wind farm and reduce loads (verwijzing). A disadvantage of yawing is an increase of the load on the turbine, and thus reducing its lifespan (Zalkind, Kanev). In addition, yawing a turbine can deflect a wake. This can be used as a method to steer a wake away from a downwind turbine, this would reduce the loads and power output. However, under unfavorable conditions it can result in an asymmetrical overlap of the wake on the downwind turbine. This can significantly increase the loads of the downwind turbine (Wilson, Van Dijk, Bastankah). As yawing of the turbine and the deflection of a wake can cause additional loads on the turbines of a wind farm, a trade of must be made between active power control and loads optimization. Axial induction can control the power output by varying the axial induction factor. Loads that are introduced by axial induction will not be discussed in this paper.

Previous studies have mainly focused on optimizing the power output, rather than controlling the power output (verwijzingen naar studies die dit hebben gedaan). Other studies focus on power optimization, while also taking the loads into account, so that an optimum is found between the two (verwijzing naar wie dit heft gedaan). The use of axial induction in optimizing power control has been marginally studied. Active power control through a combination of yaw control and axial induction control while minimizing loads is still novel.

This paper will focus on the optimization of active power control and loads by means of yaw misalignment and axial induction. In addition, a method is developed so that on-site power control can be realized.

Hier nog een overzicht van wat er in paper te vinden is. Moet later geschreven worden als de rest af is.

$$P_i = \frac{1}{2} \rho A_i C_p(a_i, \gamma_i) U_i^3 \quad (1)$$

Where,

$$C_p(a_i, \gamma_i) = 4a_i(1 - a_i)^2 \eta \cos(\gamma_i)^{pP} \quad (2)$$

Let D denote bla, m bla, blabla. The wake is simulated using

$$D_{w,i,q}(x) = \max(D_i + 2k_e m_{e,q}([x - X_i], 0) \quad (3)$$

$$U_{w,i}(x, y) = U_i (1 - 2a_i c_i(x, y)) \quad (4)$$

$$c_{i,q}(x) = \left[\frac{D_i}{D_i + 2k_e m_{U,q}(\gamma_i)[x - X_i]} \right]^2 \quad (5)$$

$$m_{U,q}(\gamma_i) = \frac{M_{U,q}}{\cos(a_U + b_U \gamma_i)} \quad (6)$$

The FLORIS model will be discussed in section II.

II. METHOD

Short introduction on method

FLORIS: The FLOW Redirection and Induction in Steady state (FLORIS) model gives a two-dimensional approximation of the steady-state effect of yaw misalignment and axial induction. It creates a wake model with equation (5 Wilson 3-3 tot 3-6). The wake is divided into three zones, q_1 to q_3 , where q_1 refers to the near wake, q_2 to the far wake, and q_3 to the mixing zone (see Plaatje). FLORIS gives a power output for each turbine, which for turbine i results in equation (Wilson 3-1). Although less accurate than a three-dimensional approximation, such as used in SOFWA, computation time is much faster for FLORIS. As a result, FLORIS can be used for on-site optimization.

FAST & MLife: FAST (Fatigue, Aerodynamics, Structures and Turbulence) is a programming tool for the simulation of dynamic (load) responses of wind turbines (by NREL) (FAST documentatie). It uses wind turbine specifications as well as wind flow situations. By evaluating a flow field, FAST computes the bending moment of a blade. MLife is an application to process the bending moment to compute the damage equivalent loads (DELs).

Inflow files, Flow field: FLORIS describes a discrete flow field of a wake, with three zones. The flow field of the wake in FLORIS is calculated with equations (numbers). The wake is divided into three zones blabla as described in FLORIS-gedeelte. A real wake will not have discrete zones (Plaatje van discrete wake), but a more fluent transition between the wake zones (Plaatje van de gaussian wake). To create a more fluent transition between the different wake-zones a Gaussian distribution of the flow field is preferred (Bastankah). The Gaussian distribution is calculated with equation (number), where the amplitude of the Gaussian, A , is equal to the velocity loss of the inner wake zone which is calculated with equation

(number). Values σ_y and σ_z , in equation (number), reflect the Gaussian standard deviation in horizontal and vertical direction, respectively. Both these standard deviations are linked to the spread of the Gaussian function. The standard deviations are linked to the outer wake zones, which are calculated by equations (numbers). In the model, σ_y and σ_z are a function of the diameter of the outer wake zone, $D_{w,i,q=3}$, which is divided by a constant. This constant is equal to 4, which results in a standard deviation of two. As a result, the central 95.45% of the values in the Gaussian distribution are taken. Wind shear can cause an important difference in velocity speeds between the rotor hub height, the end of the rotor blades at their highest points and the end of the rotor blades at their lowest point (Firtin). This velocity distribution is calculated with equation (number), where v and v_{ref} are the velocity at heights h , and h_{ref} respectively. Value α is the wind shear coefficient which depends on different factors. Coefficient α is fixed at value 0.1, reflecting a terrain type close to ocean and smooth ground (Firtin). The wind shear is implemented in the flow field.

Table 1: Overview of the minimum value, maximum value, and step size of the parameters diameter of outer wake zone (D_{wake}), freestream wind speed (U), yaw of the turbine (yaw), and the center to center distance between the center of the turbine and the center of the wake (y_{wake}).

	Minimum	Maximum	Step-size
D_{wake}	180	330	25
U	-250	250	10
yaw	-30	30	vary
y_{wake}	2	8	2

Note: Input values for yaw are [-30, -10, -5, 0, 5, 10, 30].

LUT: To reduce computational time during optimization a look-up table (LUT) is created. The LUT is created using FAST and MLife, and

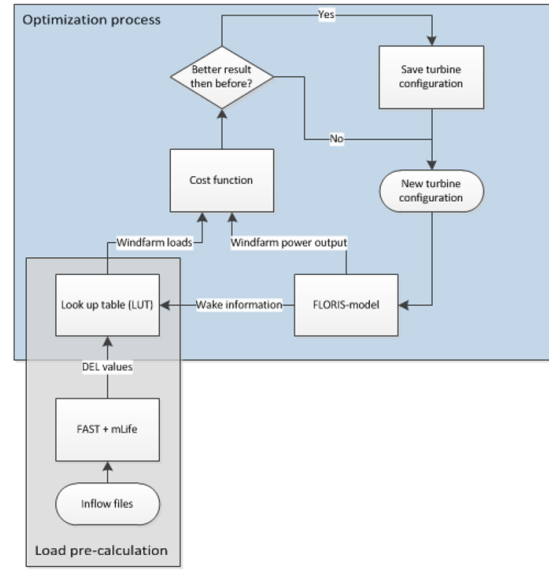


Figure 1: A boat.

it encompasses a wide variety of wind field conditions. These different conditions are described by the ranges of the parameters (see Table 1). The parameters are wake characteristics and can be extracted from FLORIS. The parameters chosen for the LUT are diameter of outer wake zone (D_{wake}), freestream wind speed (U), yaw of the turbine (yaw), and the center to center distance between the center of the turbine and the center of the wake (y_{wake}). The parameters are used to construct a flow field. Misschien nog een stukje over waarom deze parameters? Such that a four-dimensional LUT is created. The output of the LUT are the DELs. The LUT generation is time consuming, as such, it cannot account for all integer values of the parameters. The step-size of these parameters is chosen such that interpolation will give a representative result. For different parameters, different step-sizes are selected, as shown in Table (see Table 1). With the use of the pre-calculated LUT, the optimization can run more swiftly, and is able to be used on-site.

Optimization: Game Theory

- Here we introduce FLORIS, FAST, Mlife
- FLORIS: why FLORIS compared to other software? How does FLORIS work? How do we use it?
- FAST & Mlife:
- LUT: What is the LUT and why? What parameters did we choose, and why? Information about the step size of the parameters. Details in supporting info.
- Optimization: Game Theory

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

Text requiring further explanation¹.

III. RESULTS

Figures, tables with results and explanation.

Discuss what can be improved

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Prae-

¹Example footnote

Table 2: *Example table*

Name		
First name	Last Name	Grade
John	Doe	7.5
Richard	Miles	2

sent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

$$e = mc^2 \quad (7)$$

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

IV. DISCUSSION

i. Subsection One

What have we done and how to interpret the results

A statement requiring citation [Figueredo and Wolf, 2009]. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

ii. Subsection Two

Recommendations for further studies

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a,

turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

REFERENCES

[Figueredo and Wolf, 2009] Figueredo, A. J. and Wolf, P. S. A. (2009). Assortative pairing and life history strategy - a cross-cultural study. *Human Nature*, 20:317–330.