Wind Farm

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Abstract

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

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 [1], it is important for wind farms to be able to meet the demands of the power system [2]. Controlling the power output of a wind farm is essential because an overload of energy can decrease the stability of the power system [2]. 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.

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 and reduce loads of a wind farm (verwijzing). A disadvantage of yawing is an increase of the load on individual turbines, and thus reducing its lifespan [3, 4]. In addition, yawing a turbine can deflect a wake. This can be used as a method to redirect a wake from a downwind turbine, this would reduce the loads and increase power output of the downwind turbine(verwijzing). 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 [5, 6](nog meer verwijzingen). Therefore, it is necessary to understand the effects of yawing a turbine with respect to wake propagation. Axial induction can control the power output by varying the axial induction factor during the optimization. Loads that are introduced by axial induction will not be discussed in this paper. 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 minimization.

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(heb hier nog geen goede bron voor kunnen vinden). 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 control and axial induction control. 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.

II. Method

To realize active power control and minimizing loads by yaw control and axial induction, it is necessary to know the effect of different flow conditions on the total power of the wind farm and the effect of different flow conditions on the loads for each of the turbine. Moreover there need to be an optimizer which executes the optimization to obtain a set value for the power and to minimize the loads.
The total power of the wind farm is calculated in the FLORIS-model. Besides, FLORIS is able to adjust the turbine configurations, the axial induction and yaw position. The effect of loads on a turbine are given by the programs FAST and MLife. The output of these programs are Damage Equivalent Load values(DELs), which is a measure of equivalent load damage to the turbine concerning the material properties.[11] These DELs are calculated for a different set of wind and turbine conditions and are stored in a look-up table.(LUT)

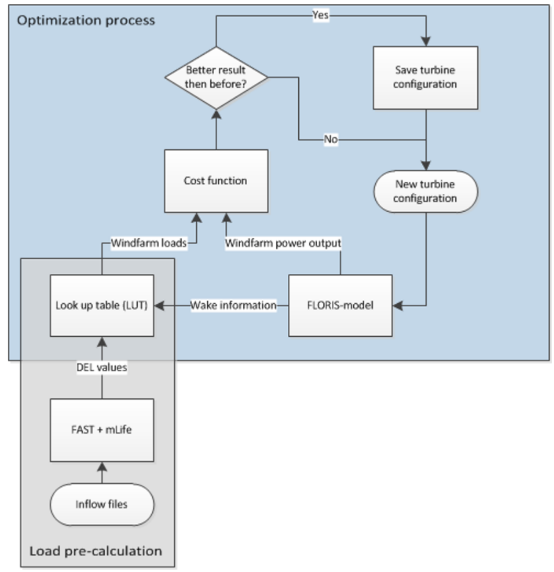


Figure 1: *Overview of the optimization procedure.*

The optimizer takes the desired power production of the wind farm as an input and uses the configurations of the turbines from FLORIS to find in the look-up table the DEL values coupled to this configurations. If the configurations of the turbines are an improvement compared to the previous one, i.e. a improved power control or a reduce in the loads, FLORIS will save the changes in turbine configurations. An overview of the optimization procedure is shown in Figure 1.

In the following sections, different models and model steps, used to perform the optimization, are explained:

i. FLORIS

The FLOw Redirection and Induction in Steady state (FLORIS) model calculates the power of the wind farm as a function of the yaw misalignment and the axial induction. [8] The advantage of FLORIS is that it is a relative accurate[6] and a low computation model, due to the fact that it uses high-fidelity data from a computational fluid dynamics simulation.

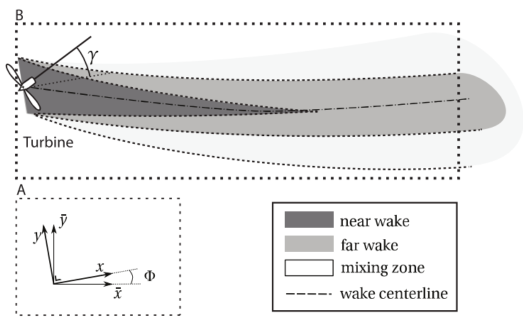


Figure 2: *Simplified top view representation of a wake of a turbine by FLORIS.[8]*

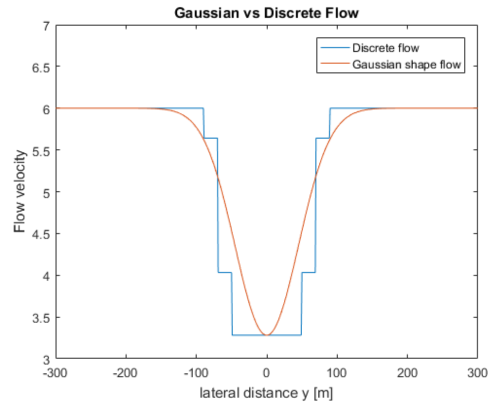


Figure 3: *Discrete wake versus Gaussian wake*

i.1 Wake modelling

As can be seen in Figure 2, FLORIS contains a wake model which divides the wake in different zones: the near wake, the far wake, and the mixing zone, $q = 1$, $q = 2$, and $q = 3$ respectively. Also wake properties as location of the centerline, the diameter of the wake zones and the wind speed in each zone are calculated by FLORIS. (1 to 2).

Let D_i denote the rotor diameter of the i^{th} turbine, k_e a coefficient that describes expansion of the zones , and $m_{e,q}$ the expansion factor which are calculated by Gebraad.[8]. The size of the wake diameter $D_{w,q,i}$ increases proportionally to the downwind distance (x). The diameter of the wake diameter is computed by,

$$D_{w,i,q}(x) = max(D_i + 2k_e m_{e,q}([x - X_i], 0) \quad (1)$$

Also the velocity depends on the downwind distance (x), which is an argument of the wake decay coefficient $c(x, y)$.2. This wake decay coefficient is multiplied by the axial induction factor and substracted from the free stream velocity U_i. The axial induction factor is a value for the decrease in wind velocity behind a turbine relative to its own rotor speed. The wake decay coefficient describes the decay of velocity for each wake zone and is defined in 3. The model parameter $M_{U,q}$, which depends on the wake zone and the yaw angle, is calculated by Gebraad.[8]

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

$$c_{i,q}(x) = \left[\frac{D_i}{D_i + 2k_e m_{U,q}(\gamma_i)[x - X_i]}\right]^2 \quad (3)$$

ii. FAST & MLife

FAST is a programming tool for the simulation of dynamic (load) responses of wind turbines (by NREL) [9]. It uses wind turbine specifications as well as wind flow situations. By evaluating a flow field, FAST computes the bending moment of a blade. Since the bending moment of a blade do not give direct information about the effect on the life-cycle time of a turbine, the program MLife is used to convert the bending moment to damage equivalent loads (DELs).

iii. 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 ((1 to 2)). The wake is divided into three zones as described in paragraph i.1. A real wake will not have discrete zones, but a more fluent transition between the wake zones. To create a more fluent transition between the different wake-zones a Gaussian distribution of the flow field is preferred [7].The difference of wake shape between a Gaussian and discrete shape can be seen in Figure 3. The Gaussian distribution is calculated as followed,

$$G(y,z) = A[e^{-(\frac{y^2}{2\sigma_y}+\frac{z^2}{2\sigma_z})}] \tag{4}$$

where the amplitude of the Gaussian, A, is equal to the velocity loss of the inner wake zone, $U_{w,1}$, which is calculated with equation 2. σ_y and σ_z reflect the Gaussian standard deviation in horizontal and vertical direction, respectively. The standard deviations are related to the outer wake zone $D_{w,i,q=3}$ which is given in 5,

$$\sigma_y, \sigma_z = D_{w,i,q=3}/n \tag{5}$$

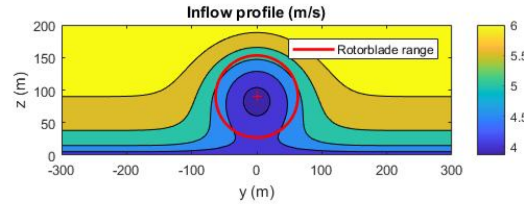
Where n can be modified to change the width of the Gaussian. Consequently, it possible to fit the Gaussian to the wake zones of Gebraad. (Figure 3)

iv. Wind shear

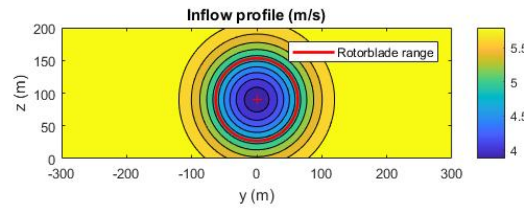
Wind shear can cause an important difference in velocity speeds between the rotor hub height, the end of the rotor blades at their highest points and the end of the rotor blades at their lowest point [10]. The velocity distribution is calculated with,

$$v = v_{ref}\left[\frac{h}{h_{ref}}\right]^{\alpha} \tag{6}$$

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 [10]. The wind shear is implemented in the flow field. The difference between a flow field with and without wind shear can be seen in Figure 4



(a) *Flow field with wind shear.*



(b) *Flow field without wind shear*

Figure 4: *Gaussian wind fields with a free stream velocity of 6 m/s at a height of 90 m. The outer diameter of de wake is 220 m and the diameter of the rotor blades is 126.4 m.*

v. LUT

To reduce computational time during optimization a look-up table (LUT) is created. The LUT is created using FAST and MLife, and it contains a a large number of DEL values for a wide variety of wind field conditions on a wind turbine. 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:

- the free stream wind speed, U
- the outer diameter of the wake, Dwake
- the yaw of the turbine, yaw
- the center to center distance between the turbine and the wake, y wake

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 each parameters

Table 1: *Overview of the minimum value, maximum value, and step size of the parameters, diameter of outer wake zone (Dwake), free stream 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
Dwake	180	330	25
U	6	8	2
yaw	-30	30	20, 10, 5
y wake	-250	250	10

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

step-sizes are selected, as shown in Table (see Table 1). With the use of the pre-calculated LUT, online optimization can be realized.

lineair interpolation is used to estimate the DEL values between the data points of the LUT. It was assumed that the DELs as a result of the windspeed(U) could be estimated accurately enough using only the 2 outer bounds. These bound were enough for the goal of this paper, though larger windfarms and different inflow wind velocities would require broadening these ranges.

The DEL effect of the Dwake was also found to be accurate enough using fairly large step-sizes. the range of this parameter was chosen so alle downwind turbines within .. and .. meters could be accurately fitted.

The y wake parameter however fluctuates over its range, and could not be accurately estimated using lineair interpolation over large stepsizes. as mentioned in... .A stepsize of 10 meters, totaling a total of 51 steps, was found to be sufficiently accurate.

The yaw parameter is chosen at a stepsize of 10 degree, howerever extra data points were added at+-5 degree to improve the accuracy in the lower yaw regeones. This effect is shown in figure 5

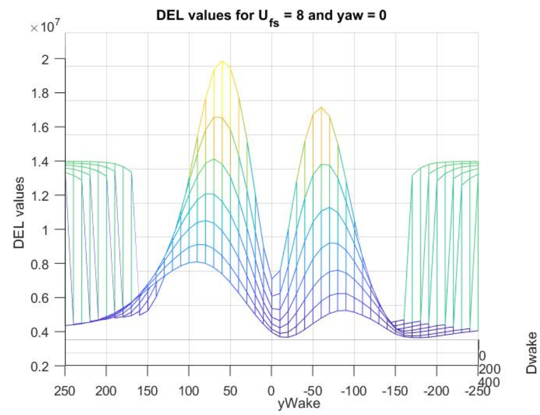


Figure 5: *page filler, not the accurate figure.*

vi. Optimization

Game Theory

III. Results

This chapter shall discribe, compare and evaluate the results of 3 optimalisation cases. The first case is used to determine the maximum power output that this 9 turbine farm can extract from the previously described windconditions, this case neglects the loads. the other 2 cases shall then be run to find the optimum running procedure when aiming for a refference power of 80 and 60 persent of the maximum power production.

Figures, tables with results and explanation:

1- realistic run to find the max power that this setup can extract from these wind conditions

2- realistic run at 80 percent of the max?

3- realistic run at 60 percent of the max?

-comparing these to echother -showing that the power does indeed aproach te ref power -comparing the loads, how do those relate to reduction of the ref power -noting the percentual(?) reduction in loads (in comparison to a base?)

– iterations – 0 ref power – ref power above max power – bandwith -jurriaan? experimenting with relevance – optimalisation factor -only loads? -only power?

IV. Discussion

What have we done and how to interpret the results

Recommendations for further studies

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