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ScienceDirect

Energy Procedia 137 (2017) 238–245

Energy Procedia

www.elsevier.com/locate/procedia

14th Deep Sea Offshore Wind R&D Conference, EERA DeepWind'2017, 18-20 January 2017, Trondheim, Norway

The effect of rotational direction on the wake of a wind turbine rotor – a comparison study of aligned co- and counter rotating turbine arrays

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Abstract

Various concepts have been investigated in wind turbine research to improve the productivity of wind farms. However, there are some strategies, which offer further potential for improvement. One of these concepts is the rotational direction of a wind turbine, which has influence on its wake characteristics and development. In this study the effect of rotor rotational direction of an upwind turbine on the performance of another wind turbine operating in its wake was investigated. Two model wind turbines with the same rotor diameter, in-line arrangement, are used for this study. The upstream wind turbine was operated either co-rotating or counter-rotating with respect to the downstream wind turbine and the distance between the turbines was varied between 2.0*D* and 5.15*D* (where *D* is the rotor diameter). The performance and wake measurements of the turbine arrays were investigated using both numerical and experimental approaches. By operating the upstream turbine in counter-rotating direction with respect to the downstream turbine, the combined productivity of the two turbines was found to have improved. This improvement is significant at 3.5D, where the productivity was observed to increase by 2.0%.

Peer-review under responsibility of SINTEF Energi AS.

Keywords: Wind turbine wake, Wind tunnel experiments, Wind farm optimization, Wake interaction, Rotor aerodynamics

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1876-6102
Peer-review under responsibility of SINTEF Energi AS.
10.1016/j.egypro.2017.10.346

Nomenclature

C_P	power coefficient	L	lift force
C_T	thrust coefficient	D	drag force
D	turbine rotor diameter	R	resulting force
TSR	tip speed ratio	C_a	axial load coefficient
U_∞	inflow velocity	C_t	tangential load coefficient
ω	angular velocity of rotor	θ	twist angle
v_θ	extra angular velocity component	α	angle of attack
u	axial velocity	φ	flow angle
v	angular velocity		

1. Introduction

Due to increasing awareness of the environmental impacts of development and the utilization of fossil fuels and nuclear energy, use of renewable energy sources for electricity generation have significantly increased globally in recent years. Herein wind energy, with a huge global potential, is playing a major role. In the last few years, a considerable part of wind energy research have been focused on offshore wind energy resources assessment and development. The interest in offshore wind resource is due to relative better wind speed and more environmental friendly nature of wind turbine in the offshore region, when compared with onshore installations. One of the main factors affecting the overall productivity of a wind farm is the wind turbine wake. The characteristics and development of a wind turbine wake depends on factors such as the operating conditions of the turbine, freestream wind conditions and site topology. The goal of the wind turbine wake study is to improve the arrangement and overall performance of a wind farm. Barthelmie et al. [1] investigated the performance of an offshore wind farm at different wind conditions. In their study, they showed that the performance between the first and second turbine row drops by about 37% at the worst case when the downstream turbine operates completely in the wake of the upstream turbine and the distance of separation between the turbines is 7D (where D is the rotor diameter). Sanderse [2] and Vermeer, Sørensen and Crespo [3] reviewed research work in wind turbine wake aerodynamics. Their reviews show that different control mechanisms have been considered to optimize the operation of a wind farm. Nevertheless, there are still some concepts of wind turbine operating conditions, which have not been thoroughly investigated and that could offer further potential for the optimization of wind farms.

One of these concepts is the application of turbine rotors rotating in opposite directions. Due to the aerodynamics of the wind turbine blade, the wake of a wind turbine rotates in opposite direction as the wind turbine rotor. By operating the two or more wind turbines in counter-rotating direction in wind farm set-up, the wind turbine wakes could be affected and hence, leads to improved performance of the wind farm. However, little attention has been given to this topic. The literature provides a few articles about small wind turbines having two rotors, which are rotating in opposite directions. Shen, Zakkam, Sørensen and Appa [4] used DTUs EllipSys3D solver to investigate a wind turbine with such a rotor. They investigated power coefficient (C_P) and thrust coefficient (C_T) for different separation distances of the rotors. They stated that C_P is almost independent of separation distance. However, in their study distance between turbines was limited to 1D. This small distances of separation offers not enough information about the effect of counter rotating rotors in a wind farm application. The same applies for the more recent study by Kumar, Abraham, Bensingh and Ilangovan [5]. They performed numerical and experimental investigations varying the distance of separation between 0.25D and 0.75D. They reported that the power increase of such a rotor is best at a separation of 0.65D. Two experimental studies investigating the effects of different rotational direction for a wind farm application were also conducted by Yuan et al. [6] [7]. They investigated turbine arrays with co- and counter- rotating rotors to find effects of the turbine rotation on the wake. In their paper, they show that the rotation direction can have a positive influence on the aligned turbine arrangement and that the power output from the downstream turbine can be increased by up to 20% for very small distances of separation (0.7D) compared to the case where the rotors are co-rotating. However, in this study, small model wind turbines with a rotor diameter of 127 mm were used and thus, their Reynolds numbers at the blade chord are in the range of around 8000 which is very low when compared with commercial wind turbine Reynolds number. Thus, the performance of the turbine could be influenced by these low Reynolds numbers.