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Power Curves in a Wind Turbine Array: A Numerical Study

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Abstract

The impact of **measuring a power curve inside a wind turbine array** is investigated using **computational fluid dynamics**. The array consists of five aligned rotors that yaw with the free-stream wind direction. The flow-field in front of a wind turbine array changes with wind direction and hence the individual power output of each turbine. By incorporating the current IEC standards on power performance measurements, the bias in the power performance of turbines in an array over an isolated rotor is determined. The **power change depends on the position of the turbine** in the array and reaches **maximally 9.03%** and **minimally -0.84%**.

Figure 1: DTU test site Høvsøre

Introduction

- Rotor thrust decelerates flow upstream continuously
- A **free-stream velocity reference** is needed for measuring the **power curve**
- **IEC standards** [1] expect the velocity reference to lie between **4 to 8 rotor radii (**R**) upstream** at hub height
- **Turbine arrays decelerate flow differently**, than a single turbine [2]
- **Changes** in the flow are directly **linked to power curves**

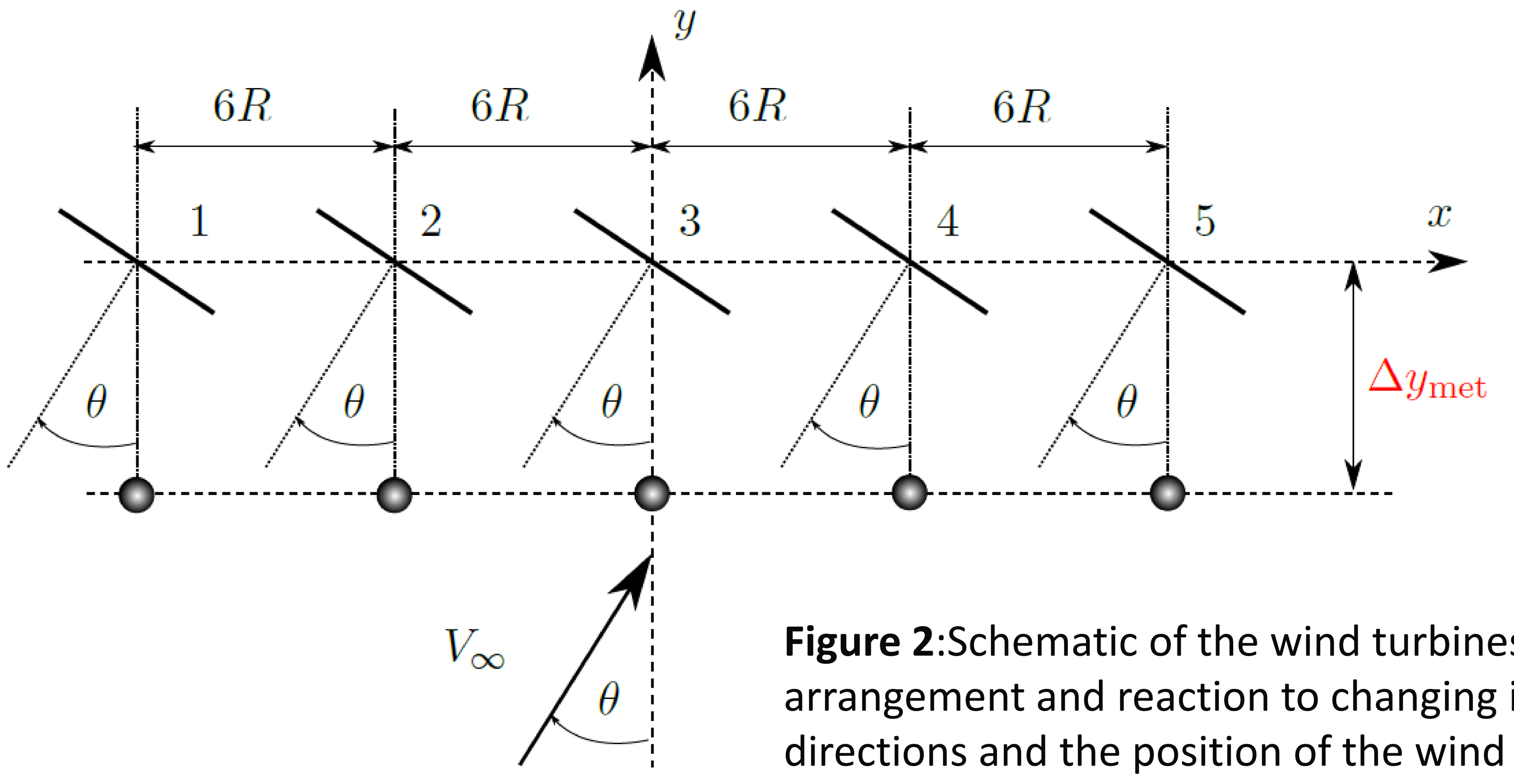

Figure 2:Schematic of the wind turbines' arrangement and reaction to changing inflow directions and the position of the wind speed measurements

Method

Computational Fluid Dynamics Simulations

- Reynolds-averaged Navier-Stokes (**RANS**) simulations with in-house solver **EllipSys3D** [3]
- Modified $k-\varepsilon$ turbulence model
- Actuator disc model for **NREL 5MW** [4] without tower nor nacelle; R = 63 m, hub at 90m
- **Sheared inflow** following log-law with roughness length $z_0 = 0.05$
- Simulations covered entire velocity range below rated: **3 m/s to 11.4 m/s** at hub height
- The **wind directions** θ were set to **0°** and **45°**

Numerical setup

- **Generic turbine arrangementt** shown in Figure 2 with **resemblance** of a common turbine **testing facility** as DTU Høvsøre (Figure 1)
- Turbines followed the wind direction θ
- Velocity was probed at hub height, Δy_{met} upstream of each turbine
- $\Delta y_{met}/R$ = 4.0, 5.0, 6.0, 7.0, 8.0

Results

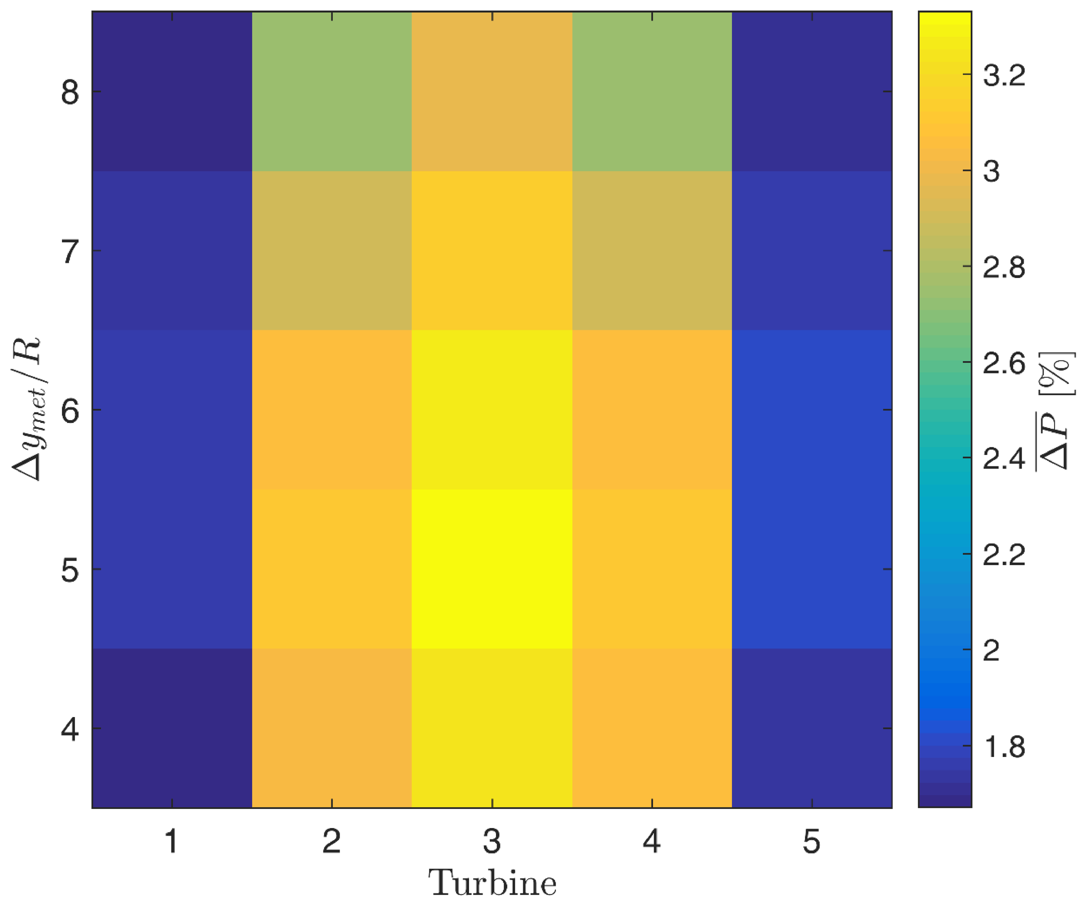

Figure 3: Average change in the power curve for an inflow angle θ of 0° as a function of the turbine and the probe location upstream.

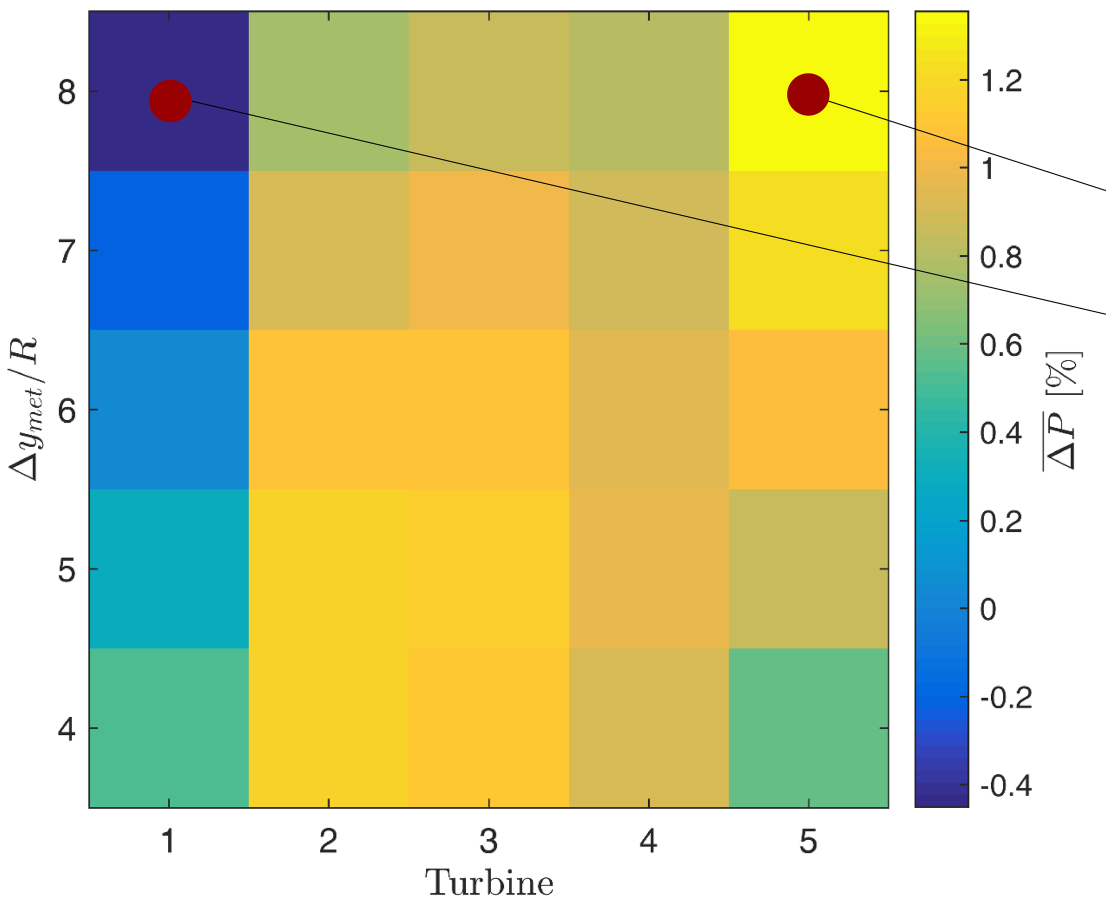

Figure 4: Average change in the power curve for an inflow angle θ of 45° as a function of the turbine and the probe location upstream.

- The difference to an isolated power curve is calculated $\Delta P = \dfrac{P - P_{iso}}{P_{iso}}$

$\max(\Delta P), \theta = 0°$ 9.03% for T3 and $\Delta y_{met}/R = 3.0$

$\min(\Delta P), \theta = 0°$ 0.84% for T1 and $\Delta y_{met}/R = 2.0$

$\max(\Delta P), \theta = 45°$ 3.03% for T3 and $\Delta y_{met}/R = 2.5$

$\min(\Delta P), \theta = 45°$ -0.84% for T5 and $\Delta y_{met}/R = 2.0$

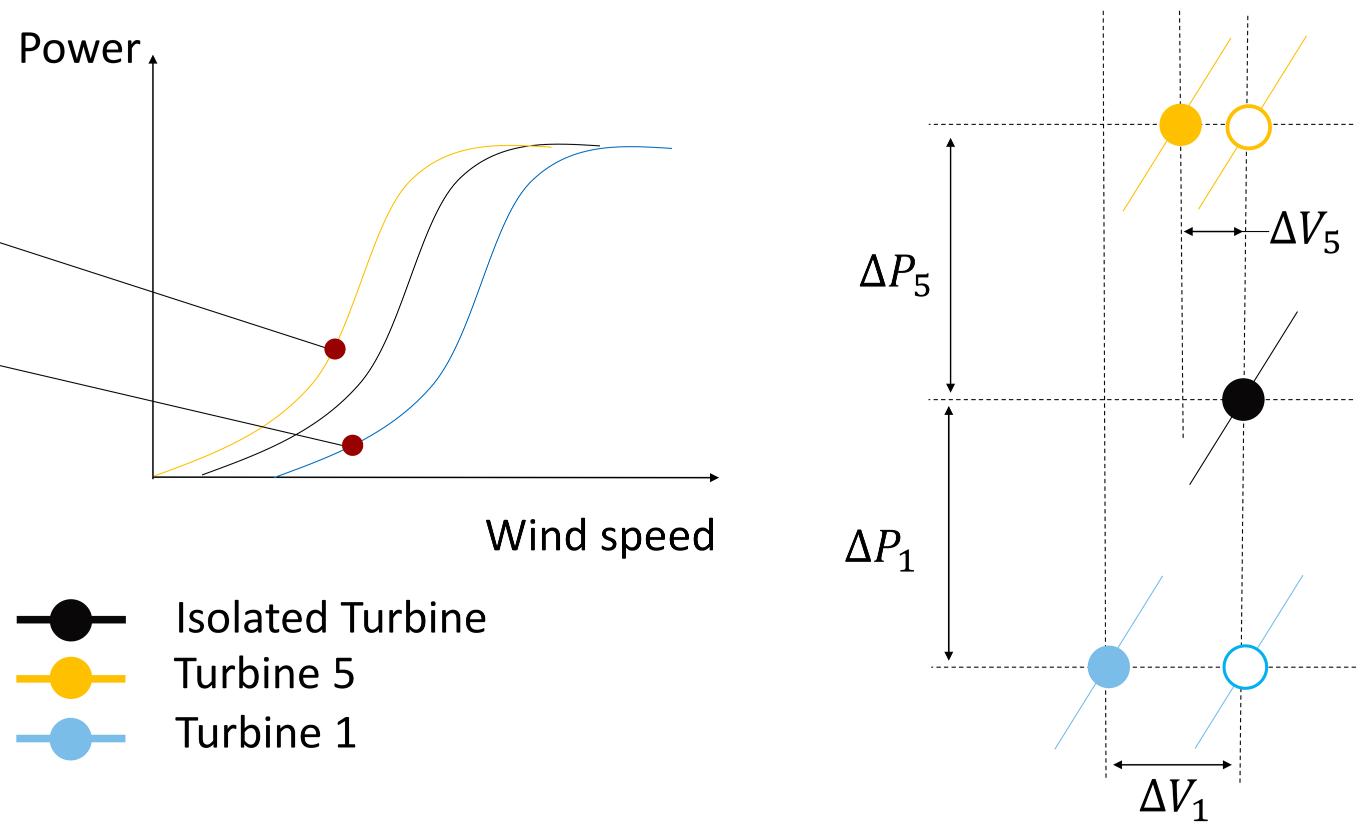

Figure 5: Demonstration of the underlying reasons for the changes in power. As outlined in detail in [2] the flow accelerates along the row of turbines, resulting in rotor **5 producing more power** than rotor 1. In fact the **power drops for rotor 1**, as it is experiencing larger deceleration upstream than an isolated turbine. However, the **changing velocities also affect the reference velocities**, making the loss in power produced by rotor 1 appear smaller as function of wind speed. Turbine 5 seems to produce even more power as its power curve is shifted to the left.

Acknowledgements

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