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CFD studies of Wind Turbine performance over 2D Hill

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Abstract

Several Computational Fluid Dynamics (CFD) simulations were carried out to investigate the effect of complex terrain on the performance of wind turbines. Terrain shape was a steep two dimensional hill. The turbulence model used was the Large Eddy Simulation (LES) model. Fully resolved wind turbine blades were used in these simulations. CFD simulations showed that complex terrain greatly affects wind turbines performance. Power output changes according to the position of the wind turbine over the complex terrain, and wind turbine wake development in a complex terrain is different from that in a flat terrain.

1. Introduction

Wind turbines are grouped together to form a wind farm aiming for cost reduction, but there are several problems arise when a group of wind turbines are put close to each other. The first row of wind turbines extracts kinetic energy from the wind, which results in a decrease in wind speed, therefore the second row of wind turbines produce less electricity than the first row [1]. Another problem is that wind is turbulent in the wake of the first row, and that increases the stresses and fatigue applied on the second row, and that leads to the reduction of wind turbine life time [1]. Wind farm terrain shape must be considered during the optimization of wind turbines location, as the terrain can have an impact on the total power generated by the wind farm and the life time of wind turbines, also complex terrains can induce turbulence which can apply stresses and affect the life time of wind turbines, it can also have an effect on the shape of wake velocity profiles of wind turbines [2]. Several CFD simulations were carried out to investigate the effect of complex terrains on wind turbines performance. The first case was a simulation of wind flow over 2D hill, the second case was a simulation of a fully resolved wind turbine rotor over flat terrain. Finally, the third case was a simulation of a fully resolved wind turbine rotor over 2D hill.

2. Method

Helyx-OS ™ [3], which is an Open-Source Graphical User Interface for OpenFOAM ® [4], was used to perform the CFD simulations. ParaView [5], which is an open-source data analysis and visualization application, was used for visualization and post processing of results. Various simulations were performed to investigate the effect of complex terrains on wind turbines performance.

2.1. CFD simulation of wind flow over 2D hill

In this simulation the complex terrain was a two dimensional hill as shown in Fig 1 and represented by equations (1), (2), and (3). Where h is the height of the hill and equals to wind turbine diameter D, and S is the slope of the hill and equals to 0.45.

$$z = h\, e\text{^}(-0.5((x/\sigma)\text{^}2)) \quad (1)$$

$$\sigma = L/1.1774 \quad (2)$$

$$L = h/2S \quad (3)$$

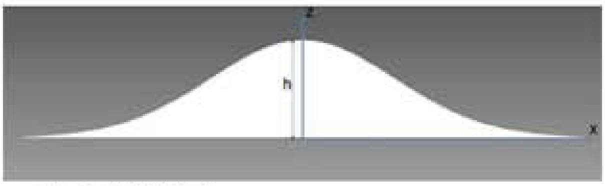

Fig. 1. 2D hill shape

2.2. CFD simulation of a fully resolved wind turbine rotor over flat terrain

A fully resolved wind turbine rotor was used in this simulation. The dimensions of the computational domain were about 7.8D × 13.7D × 7.8D. The diameter of the wind turbine was D. The inlet wind velocity was u. Top, bottom, and side walls were set to slip conditions. The turbulence model used was the Smagorinsky Large Eddy Simulation (LES) model.

2.3. CFD simulation of a fully resolved wind turbine rotor over 2D hill

The diameter of the wind turbine was D. The dimensions of the computational domain were about 9D×40D×10D. The inlet wind velocity was u. Side walls, ground inflow region, and top wall, were set to slip conditions, while the hill and ground downstream region were set to no-slip condition. The turbulence model used was the Smagorinsky Large Eddy Simulation (LES) model.

3. Results and discussion

Figure 2 shows the flow visualization of the instantaneous flow over the two dimensional hill. The wind velocity increases at the top of the hill and decreases at the downstream region. Unsteady vortices are created when the air flows over the hill.

Power generated by the wind turbine at the top of the 2D hill is higher than that of a wind turbine in flat terrain, that is because of wind acceleration over the top of the hill, resulting in greater power output. Figure 3 shows the wind turbine wake development over flat terrain, while Figure 4 shows the wake development of the wind turbine over the 2D hill. By comparing Figure 3 and 4, it may be concluded that the shape of the wind turbine wake over 2D hill is curved towards the ground compared to the wake shape of a wind turbine over a flat terrain.

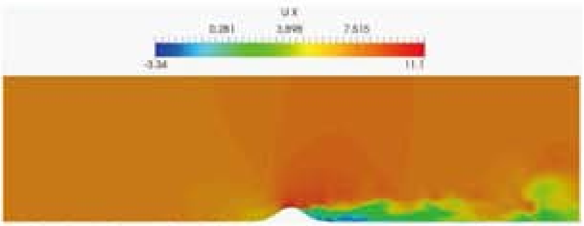

Fig. 2. Flow visualization of instantaneous flow over 2D hill

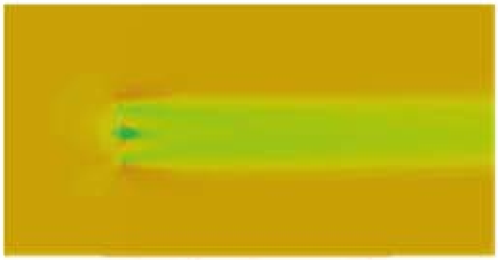

Fig. 3. Wind turbine wake over flat terrain

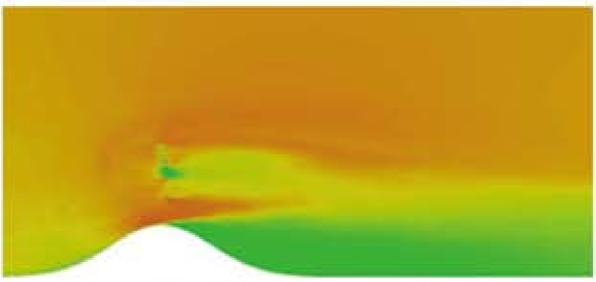

Fig. 4. Wind turbine wake over 2D hill

4. Conclusions

Power generated by the wind turbine at the top of the 2D hill is higher than that of a wind turbine in flat terrain, that is because of wind acceleration over the top of the hill, resulting in greater power output. The shape of the wind turbine wake at the top of the 2D hill is curved towards the ground compared to the wake shape of a wind turbine in a flat terrain.

Wind farm terrain affects the performance of wind turbines and wake development. Wind farm terrain shape must be considered during the optimization of wind turbines locations, as the terrain can have an impact on the total power generated by the wind farm.

References

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