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Efficiency of large wind farms: investigation of dependency on turbine technology and cluster layout

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***Abstract*—The installed wind power has increased significantly in the last decade and is predicted to increase further. With more installed wind power it can be expected that eventually wind farms will increase in size. Due to the wind speed reduction inside wind farms and the related power losses, it becomes important to understand to which extend the power production per unit area in large wind farms will be lowered.**

Previous studies have suggested that the power density of very large wind farms could generally be limited to $1\,\mathrm{W\,m^{-2}}$. However, our latest results from mesoscale model simulations of single very large wind farms with a given turbine type have shown that the wind speed and therefore also the power density depends on the local wind speed conditions, and installed capacity density, and surface roughness.

Here, we first show that even for very large wind farms the velocity reduction inside a wind farm remains wind speed dependent and does not converge to a universal value as has been assumed previously. Then, we advance on our previous study and show how the wind farm power density and the efficiency varies for different wind farm layouts.

I. Introduction

An increase in the share of low carbon energy sources requires additional wind farms to be installed. Therefore, it can be expected that – especially in windy regions – wind farms will increase in size. This tendency is for example already visible in the North Sea . In 2002, the first large offshore wind farm Horns Rev I had a rated capacity of 160 MW, whereas in 2013 the largest offshore wind farm, the London Array, had a rated capacity of 630 MW. From the planned wind farms (4coffshore), it can be noticed that already today clusters of wind farms are arising (e.g. at Horns Rev or Rødsand), which eventually could emerge to very large wind farms (e.g. in the German Bight).

With an increasing number of installed wind farms, it becomes not only important to study the wind speed development inside wind farms, but also the wind recovery in the wake of wind farms, when wind farms are placed close to each other.

Recently, we have shown with Numerical Weather Prediction (NWP) Model simulations that also for very large hypothetical wind farms the wind speed inside the wind farm and therefore the power density strongly depends on the regional wind conditions, on the local surface roughness and on the turbine density [9]. The power density in a very large wind farm ($100.000\,\mathrm{km^2}$) in offshore regions with very strong winds could be up-to $3.5\,\mathrm{W\,m^2}$. This is 3.5 as much as has been assumed previously [1], [5].

In the same study, we found that in offshore regions with strong winds – representative for the North Sea – the efficiency losses for very large wind farms compared to smaller wind farms were higher than in the other considered regions. Therefore, we concluded that in the North Sea clusters of smaller wind farms would offer the highest potential.

Here, we extend on our previous study and first analyse the wind speed reduction in a single very large wind farm for different turbine types. Then, we investigate how the efficiency and Annual Energy Production (AEP) of a cluster of 2 hypothetical wind farms will change with a variation in turbine density.

A. Methodology

We use the Weather Research and Forecast (WRF) model [7] with two wind farm parametrisations [4], [8] to simulate the wind speed inside and in the wake of wind farms in three regions. The first region is onshore (Region A) with moderate winds (median $7.4\,\mathrm{m\,s^{-1}}$), representative for the Great Plains. The second area is offshore (Region B) and represents with strong winds (median $9.1\,\mathrm{m\,s^{-1}}$) the North Sea. The third area (Region C) has very strong winds ($13.1\,\mathrm{m\,s^{-1}}$) and is representative for regions such as the Strait of Magellan or the Gulf of Suez in Egypt.

The simulations use "idealised" forcing conditions to drive the WRF model. Regional wind conditions are then obtained from a series of simulations that range between the turbine cut-in and cut-out wind speed. The surface roughness over water was obtained from the Charnock formulation [3].

First, we simulated the flow in single wind farms that ranged from $25\,\mathrm{km^2}$ to $114.000\,\mathrm{km^2}$. The wind farms were equipped with Vestas V80 (2 MW) turbines that had a hub-height a 70 m.s.a.l.. The installed turbine density varied from $2.8\,\mathrm{W\,m^2}$ to $11.3\,\mathrm{W\,m^2}$.

In the second experiments the total cluster area is set to a square of $3.600\,\mathrm{km^2}$, which is comparable to the Dogger Bank area that surrounds the planned Creyke Beck and Teesside wind farms. We investigate the wind farm and wind farm cluster AEP and efficiency for different wind farm spacings and 2 turbine densities. The distance between the wind farms ranged between zero, where the two wind farms were connected, to around 30 km. The total number of turbines was 18.289 and 25.605, respectively. For the in total 8 wind farm cluster configurations (4 wind farm spacings and 2 turbine densities), we performed simulations with converged wind speeds between the cut-in and cut-out wind speed in $1\,\mathrm{m\,s^{-1}}$ intervals.

B. Results

We will show how the wind farm and wind farm cluster energy yield and efficiency depends on the choices in wind farm cluster configuration and the regional wind conditions.

These results are a natural extension of the method and results in [9]. As an indication of the first results for wind farms in a high surface roughness setting, very large wind farms with low installed capacity density and placed back-to-back can be the rational choice. For wind farms in a low surface roughness setting, smaller wind farms with higher installed capacity separated with turbine free recovery zones can be the better option.

II. Conclusion

This is a novel and methodology, which is economical on computer resources. Therefore, it allows to evaluate the energy yield for different climates, turbine technologies, and wind farm cluster configurations.

The presentation will give the audience results and prospective of the application of new mesoscale wake modelling that is highly relevant for the planning of long term and large scale exploitation of wind energy in the future.

In these experiments, we suppose a regular turbine spacing inside the wind farms. In the future, the presented methodology can also be applied to study the interaction between irregular wind farms that are designed to minimise their internal wake losses.

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