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Experimental Study of Turbulence Influence on Wind Turbine Performance

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Regarding the issue about unmatched Reynolds number for downscaled wind turbine tests in wind tunnels, a study of the performance characteristics of a model wind turbine operating in the wake of another turbine of the same model under laminar and turbulent inflow was performed. The distance between the two turbines was set at 5, 10, and 15 turbine diameters. In the laminar inflow case, due to the low recovery rate in the wake of the front turbine, the efficiency of the rare turbine has been greatly reduced even when the distance was 15 diameters. To address this issue, turbulent inflow was created using an active grid system installed between the contraction and test-section of the wind tunnel; the maximum turbulence intensity can reach 203. Velocity fields upstream and in the wake of the turbine were measured using a 2D-PIV system; 1000 pairs of images were acquired for each location to achieve statistical convergence. It was found that by using turbulent inflow the efficiency of both the upstream and the downstream turbine was highly improved. Also, it was found that the efficiency of both turbines is highly related to the turbulence intensity in the inflow. At a constant tip speed ratio for the upstream turbine of 10.3, and a distance of 5 diameters between them, the efficiency for the downstream turbine was 4.1 times higher than in laminar case; for 10 and 15 diameters with the same conditions it was 2.71, and 2.48 times higher respectively. The maximum efficiencies reached for the downstream turbine were 38.53, 34.53, and 24.63 for 15, 10, and 5 diameters of distance between respectively. Therefore, despite the low Reynolds number, a high efficiency close to the field was reached using turbulent flow created by an active grid system.

METHODS AND RESULTS

Experimental Setup

In this study, two-blade wind turbines with a 20.3cm diameter (D=20.3cm) were used. Two wind turbines were installed in a low-speed wind tunnel with test-section dimension of 1.4mx1.4mx14.6m. Distance between the wind turbines was adjustable. An active grid system was used to generate controllable inflow turbulence. An ATI Nano force and torque sensor was used to measure the efficiency of the turbines and a 2D planer PIV system was used to measure the flow fields up- and downstream of the turbines. A schematic of the experimental setup was presented in Figure 1, in which the distance between the two turbines was set at 10D.

(Please see figure in the attached file.)
Figure 1. Wind turbines array and PIV testing sections

Efficiency Measurements

Using a torque sensor (NANO 7 IP68) mounted on the wind turbines the harvested energy and efficiency of the turbines were studied. These experiments were conducted in two turbines, operated with one turbine in the wake of another under laminar and turbulent flow inflow conditions. Two variables were manipulated in the experiment: the distance between turbine and turbine, e.g. 5D, 10D and 15D (, where D is the diameter of the turbine); and the tip-speed-ratio (TSR) of the upstream wind turbine. For the laminar case, the tip speed ratio of the upstream wind turbine was set at 8 different ratios within the rage of 5.6-8.9. And for the turbulent case, within the range of 4.7-10.9. For both cases, the harvested energy was calculated using the product of torque and the angular speed of the turbine. Some results of the downstream turbine are presented in figure 2, in which the upstream wind turbine tip speed ratio was set at 10.3 for turbulent flow, and 5.6 for laminar flow.
(Please see figure in the attached file.)
Figure 2. Downstream wind turbine power coefficient versus tip speed ration for a) 5 diameters, laminar flow, b) 5 diameters, turbulent flow, c) 10 diameters, laminar flow, d) 10 diameters, turbulent flow, e) 15 diameters, laminar flow, f) 15 diameters, turbulent flow.
From Figure 2, great improvement in turbine efficiency was found when the inflow is turbulent. For the case using a 5D distance, the maximum efficiency was 4.1 times higher using turbulent flow. For the 10D and 15D distances, the maximum efficiency was 2.71 and 2.48 times higher respectively. Which provided efficiencies

much closer to the ones in the field than the laminar performance.

PIV Measurements

To understand why the wind turbine performance increased in turbulent flow condition, 2D PIV measurements were taken in various regions. In each region, 1000 pairs of particle images were acquired to achieve statistical convergence. The locations for PIV measurement were shown in Figure 1. These locations were chosen to study the flow recovery downstream of the turbines and the influence of turbulence intensity. For each conditions, flow upstream of the front turbine was also measured. The PIV measurements were performed using a high (103) and low (33) turbulence intensity in the inflow so a comparison on the flow using these two can be made.
In figure 3, the velocity profiles for the four regions under high and low turbulence intensity are presented, notice that the velocity magnitude has been normalized using the free stream velocity. The corresponding turbulence intensity contours were presented in figure 4. In region 1, the inflow is approximately uniform before approaching the wind turbine. In regions 2 and 3, the turbulence intensity was still higher for the high turbulent inflow case, which caused fast velocity recovery in the wake. This explained the significantly greater efficiency in the rare wind turbine under turbulent inflow conditions.

(Please see figure in the attached file.)
Figure 3. Normalized velocity profile in the 4 measurement regions indicated in Figure 1. First row: high turbulence intensity (TI=103); second row: low turbulence intensity (TI=33)

In region 4 the turbulence intensity was comparable to that in regions 2 and 3, approximately 303, for both low and high TI cases (see figure 4). The velocity profiles for this section were similar as well (figures 3). This is because the turbulence intensity downstream of the second turbine is almost independent of the inflow turbulence, due to the disturbance generated by the two turbines.

(Please see figure in the attached file.)
Figure 4. Turbulence intensity in the 4 measurement regions indicated in
Figure 1. First row: high turbulence intensity (TI=103); second row: low turbulence intensity (TI=33)

CONCLUSIONS

An experimental investigation has been performed to find a solution regarding the issue of unmatched Reynolds number for downscaled wind turbines test in wind tunnels. A wind turbine was tested operating in the wake of another turbine under turbulent inflow conditions with different turbulence intensity. It was found that the efficiency of both turbines, upstream and downstream, had highly improved when the inflow was turbulent. Also PIV measurements were taken in the wake of both wind turbines. It was concluded that the flow recovery in the wake downstream of the first wind turbine highly depends on the turbulence intensity in the inflow. For a higher turbulence intensity, a faster recovery has been observed. However, it was also found that the flow recovery downstream the second turbine was almost not influenced by the initial turbulence intensity. At this point the flow was greatly affected by the two wind turbines and the initial conditions of the inflow, in terms of turbulence, were no longer important.