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A numerical study of the effect of the central shaft on the performance of a VAWT

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Abstract

Vertical axis wind turbines (VAWT) have recently received growing interest for application in urban environments due to their omni-directional capabilities. However, further research is required to optimize their performance. The central shaft is an inseparable part of a VAWT whose effect on turbine performance is currently not fully understood. In this paper the effect of the central shaft on the power coefficient (\(C_P\)) and thrust coefficient (\(C_T\)) of a VAWT is studied for different shaft-to-turbine diameter ratios (\(\gamma\)) using 2D unsteady Reynolds-Averaged Navier-Stokes (URANS) CFD simulations. The study shows that the presence of the shaft with \(\gamma=4\%\) results in a 2.5\% and 1.1\% reduction in \(C_P\) and \(C_T\), respectively. This is mainly due to the wake of the shaft which results in a region of lower velocity directly downstream and a dip in the moment coefficient and thrust force at an azimuthal position of 270°.

1 Introduction

Vertical axis wind turbines have regained interest during the last decade due to their omni-directional capabilities and the growing interest in harvesting wind energy in urban environments where this feature is highly desirable (Gsenger & Pitteloud, 2015). However, a significantly lower amount of research in the past three decades has resulted in VAWT performance falling behind that of their horizontal axis counterparts. Further research is therefore required on performance optimization of VAWT in urban environments (Rezaeiha et al., 2016b). Several research efforts have highlighted the complexities of the flow around a VAWT (Rezaeiha et al., 2016a; Simão Ferreira et al., 2008; Tescione et al., 2014). The central shaft is an inseparable component of the turbine which affects the flow in the centerline of the turbine, though its effect on turbine performance is largely unknown. Therefore, the current study investigates the effect of the central shaft with different shaft-to-turbine diameter ratios on the power and thrust coefficient of a VAWT in order to develop effective optimization strategies. The results of the CFD simulation are validated with experimental data.

2 VAWT geometry, mesh and computational settings

A 2-bladed H-type VAWT with straight blades was simulated. The turbine has a diameter (D) of 1 m and a solidity (\(\sigma\)) of 0.12. The blade sections were typical VAWT symmetric NACA0018 airfoil with a chord (c) of 0.06 D oriented normal to the radial line from the center of rotation. The turbine shaft diameter was 0.04 D (\(\gamma=4\%\)) and the shaft was rotating in the same direction as the turbine. The turbine was operated at a tip speed ratio (\(\lambda\)) of 4.5. The freestream velocity was 9.3 m/s and the rotational speed (\(\omega\)) is 84 rad/s. The approach-flow turbulence intensity of the freestream was 5\% while the incident flow turbulence intensity was 3.96\% (Blocken et al., 2007). The simulation was performed on a computational domain of 40D length \(\times\) 20D width and a mesh of 526,006 cells using
the commercial CFD software package ANSYS Fluent version 16.1 using URANS calculations. A steady-state RANS result was used for initialization and final data were sampled after 20 revolutions of the turbine. Turbulence modeling was done using the 4-equation transition SST turbulence model (Menter et al., 2006). Sensitivity analyses for domain and mesh size, azimuthal increment and number of revolutions of the turbine were performed to ensure accuracy of the results.

3 Results and discussion

In order to validate the results normalized instantaneous streamwise velocities at x/R of 1.5 were compared with experimental results (Tescione et al., 2014) for which the turbine geometry and operational settings were the same. The average deviation from the experimental data was 12%. Comparison of the results for cases with and without the central shaft showed that the wake generated by the shaft, visible as a region of lower velocity, results in temporary reductions of the moment coefficient and thrust force when the blade passes downstream of the shaft. This resulted in a 2.5% reduction in $C_P$ and a 1.1% reduction in $C_T$ compared to the case without the shaft (see Table 1) for $\gamma=4\%$. The full paper will include results for other $\gamma$-values as well as a comparison with a stationary shaft with a rough surface.

<table>
<thead>
<tr>
<th>Performance parameter</th>
<th>Shaft-to-turbine diameter ratio</th>
<th>$C_P$</th>
<th>$C_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without shaft</td>
<td>-</td>
<td>0.40</td>
<td>0.89</td>
</tr>
<tr>
<td>With shaft</td>
<td>4%</td>
<td>0.39</td>
<td>0.88</td>
</tr>
</tbody>
</table>

4 Conclusion

CFD simulations of a VAWT with and without a rotating central shaft were conducted using URANS calculations with Transition SST turbulence modeling. The results showed that the central shaft with a shaft-to-turbine diameter ratio of 4\% results in a 2.5\% reduction in $C_P$ and a 1.1\% reduction in $C_T$ compared to the case without shaft. The final results including various $\gamma$-values might be used to minimize the shaft effect.

References