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Numerical and Experimental Evaluation of High-Efficiency Savonius Type Wind Turbine at Low Reynolds Number

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Extended Abstract

Classical Savonius-type wind turbines (SWT) with semi-circular blades were shown to achieve peak power coefficient (efficiency or c_P) up to 25% [1]. The peak power coefficient values were achieved only at relatively high Reynolds number (Re>800k). This was initially shown only using wind-tunnel investigations, and these results were strengthened by many subsequent numerical studies which have shown good correlation with the experimental data. In recent SWT research, the objective is mostly related to increasing relatively low SWT efficiency. One of the notable SWT blade shape modifications to show significant improvement was proposed by Bach and Benes in [2]–[4]. The modified blade shape was composed a straight part in the inner rotor part and a circular-arc (spanning less than 180°) on the outer part. The peak power coefficient was increased from 22% to 28%. Different recent studies attempted further improvement using complex curves such as elliptical [5], spline [6] or multiple smaller quarter [7], with no major improvement. A major improvement was achieved in numerical shape-optimization studies with the novel "scooplet-based" SWT [8] with efficiency increased to 37% using 2D CFD and 34% using 3D CFD [9].

In previous numerical studies, the Reynolds number is usually fixed at relatively large values near Re=1M. However, this number is difficult to achieve in small-scale wind tunnels. In the current study, an experimental study of the optimized SWT turbine was performed in low-speed wind tunnel at Reynolds number 130k. The experiments were first performed for the classical SWT for which the expected results are known from previous studies. The improvement of the novel desing was then measured relative to the classical SWT design. The experiments were performed at a fixed wind velocity equal to v=5.6 m/s. The rotor diameter in all cases was D=0.36m (r=0.18m) and height H=0.4m. The rotational speed ω was controlled using a DC generator connected to variable resistor. The tip speed ratio (TSR=$r\omega/v$) was varied between TSR=0.5 and TSR=1.25. The electrical power was measured from the generated current (I) and the voltage (U) over resistor. The static mechanical torque (T_0) was measured independently of the electrical power, and the estimated aerodynamic power was calculated by $P=UI/\eta+T_0\omega$. The main unknown is related to generator efficiency η. However, the same setup was used for measuring both turbine types, so that the relative difference should be reliable. To complement the experimental results, numerical analysis was performed using the same setup as in the experiment. The same 3D CFD model as in [9] was used, but with the geometry matching the performed experiment.

For classical SWT, the peak power coefficient at Re=130k was estimated using CFD to be 21% at TSR=0.8. In the experimental data, the highest aerodynamic power also happened to be at TSR=0.8 with c_P=19%. The peak power coefficient of the novel SWT using CFD was 29% also at TSR=0.8. Meanwhile, the experiment show peak efficiency of 26% at TSR=0.9 (which was only slightly lower at TSR=0.8). This is a 37% relative improvement of the novel design over the classical SWT. The CFD results and previous experimental studies predict that the power coefficient will significantly increase at higher Reynolds number which will be the topic of a future work.

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