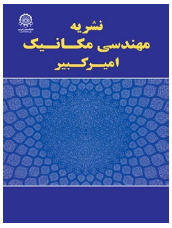

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Performance Investigation of Hybrid Darrieus-Savonius Wind Turbine Compared to Straight-Bladed Darrieus Turbine by Three-Dimensional Numerical Simulation

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ABSTRACT: The purpose of this research is to investigate the performance of hybrid Darrieus-Savonius wind turbines to achieve a model with high starting moment and suitable performance conditions. Straight-bladed Darrieus wind turbines have high-amplitude fluctuations in moment and, at some angles, this moment is not enough to start the turbine motion. The hybrid turbine is compared with two equivalent models of straight-bladed Darrieus wind turbines. The first model has equal available power and the second model has equal height with the hybrid turbine. Three-dimensional simulation is performed using computational fluid dynamics and solving unsteady Reynolds averaged Navier-Stokes equations with finite volume method, using turbulence model and rotating mesh for rotation of the turbine. According to the results, at the self-starting, the hybrid turbine possesses 22.24% and 17.5% less standard deviation and 69.8% and 56.9% more average moment, respectively, compared to the first and second equivalent turbines. In operational mode, the hybrid turbine at the rotational speed of 30 RPM possesses 16.1% and 27.3% less standard deviation and 19.1% and 1.03% more average moment, respectively. Therefore, the hybrid turbine at the self-starting, as well as at low rotational speeds, possesses more average moment and less fluctuations compared to equivalent Darrieus turbines.

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1- Introduction

One of the most effective method to improve starting moment of straight-bladed Darrieus wind turbines is combination of Darrieus with Savonius turbine. For small scale turbines, it would recommend to place Savonius part below the Darrieus part [1]. When the Savonius blades are not overlapping and three blade are used, hybrid turbine has the highest power [2]. Elliptical shape of Darrieus turbines just has positive effect when the Savonius part is placed inside it [3].

The present study is concerned with expressing a hybrid turbine to reach suitable operating conditions and improve performance of straight-bladed turbines with recommended conditions according to previous studies.

2- Three-Dimensional Modeling

As shown in Fig. 1 and Table 1, H2 and H3 are heights of the Darrieus and Savonius part respectively. NACA0021 airfoil with chord length of 0.3 m is used for straight blades.

Table 1. Turbine characteristics

Turbine characteristics	Length, m
H_2	1.15
H_3	0.4
Rotor radius of Darrieus part (R)	0.99
Rotor radius of Savonius part (r_1)	0.45
Thickness of half cylindrical (t)	0.005
Radius of half cylindrical (r_2)	0.15

To compare the hybrid turbine with straight-bladed turbine, two different heights are considered. The first, has equal available power (H=1.45 m) and the second, has equal height (H=1.6 m).

3- Governing Equations and Solving Methods

Three-dimensional simulation is performed using Computational Fluid Dynamics (CFD) and solving Unsteady Reynolds Averaged Navier-Stokes (URANS) equations with finite volume method, using turbulence model and rotating mesh for rotation of the turbine. Fluid flow is considered to be viscous and incompressible. Near wall of the blades, standard wall function is applied.

4- Computational Domain and Mesh Generation

The flow field is a rectangular cube (32R×12R×12R). The fluid is air in standard conditions. As shown in Fig. 2, direction of free stream flow is the same with X axis and it has constant speed of 7 m/s. The turbine rotation is around Z axis and the

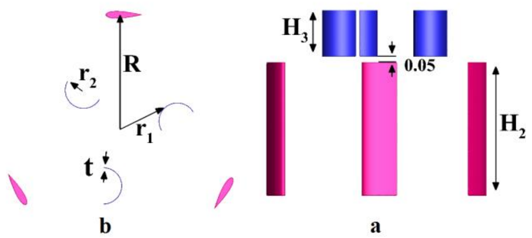

Fig. 1. Hybrid turbine model

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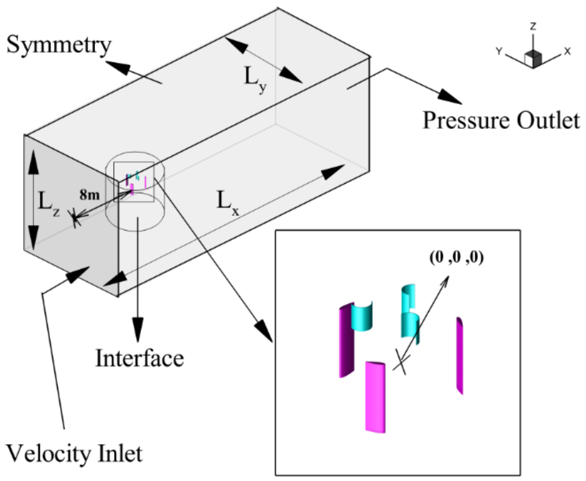

Fig. 2. The flow field and boundary conditions

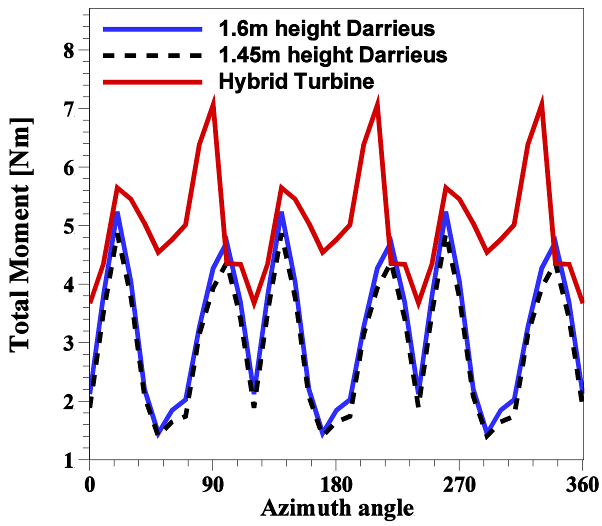

Fig. 4. Comparison of total moment vs. azimuth angle for starting mode

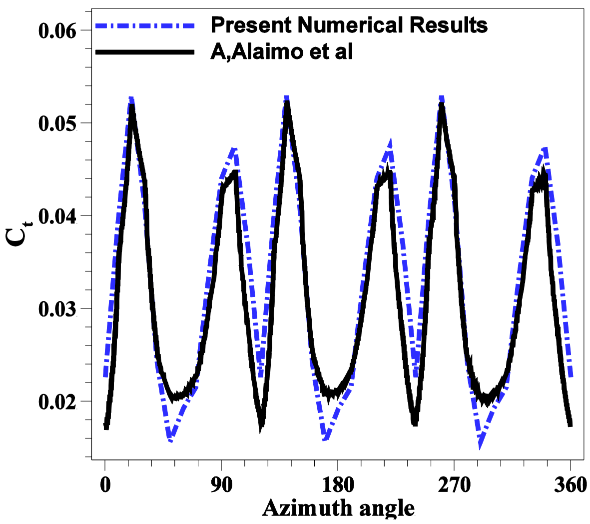

Fig. 3. Verification of straight-bladed turbine total moment coefficient

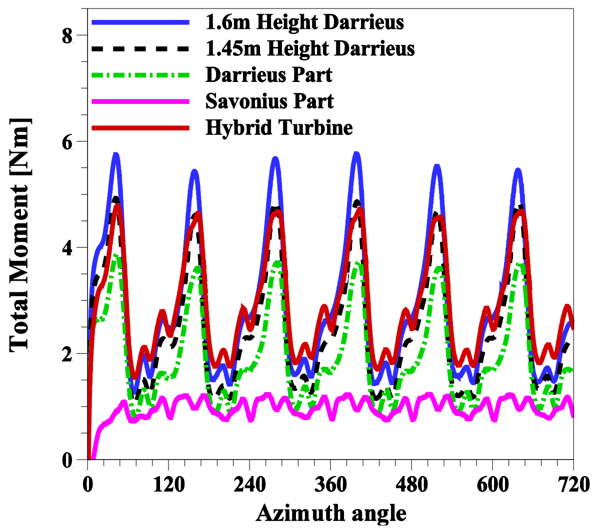

Fig. 5. Comparison of total moment vs. azimuth angle for 30 RPM

azimuth angle of turbine indicates the position of the turbine blades. The zero angle of azimuth corresponds to positive Y axis direction and increases with turbine rotation. For hybrid turbine, Darrieus part is used as reference of azimuth angle. To reduce the moment fluctuations of Darrieus part, optimal azimuth angle between two parts of hybrid turbine has been determined. The generated mesh is also unstructured with structured mesh in boundary layer.

5- Verification

The numerical research of Alaimo et al. [4] has been used as reference. The number of cell used in reference [4] is 9503471. The cell number of present study is 1400000. As shown in Fig. 3, considering the computational time and cost, it seems by 85% reduction in the number of cells, good agreement is obtained

6- Results and Discussion

At the self-starting mode, Fig. 4, hybrid turbine in comparison with straight-bladed turbines possesses 56.93% and 69.72% more average moment and 22.36% and 17.522% less standard deviation, respectively, compared to the first and second straight-bladed turbines. In operational mode, at 30 RPM as shown in Fig. 5, hybrid turbine in comparison with straight-bladed turbines possesses 1.03% and 19.1% more average moment and 27.3% and 16.1% less standard deviation respectively.

To get the negative effect of increasing rotation speed of the Savonius part on hybrid turbine, speed of 60 RPM, as shown in Fig. 6, is examined. At 60 RPM, hybrid turbine in comparison with straight-bladed turbines possesses 54.3% and 37.6% less average moment and 21.6% and 11.6% less standard deviation respectively.

7- Conclusion

• Considering performance of the hybrid turbine at the starting mode and different speed rotations, the hybrid turbine

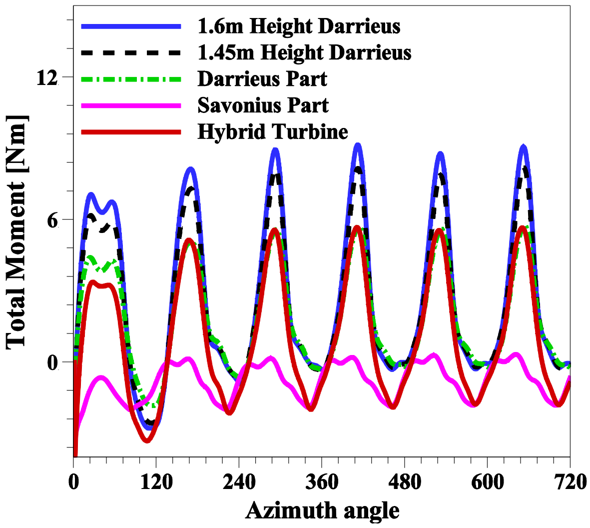

Fig. 6. Comparison of total moment vs. azimuth angle for 60 RPM

is among low rotational speed turbines. The hybrid turbine at the self-starting condition, as well as at low rotational speeds, possesses more average moment and less fluctuations compared to straight-bladed turbines.

• Generally, the hybrid turbine seems to be perfectly suitable for low rotational speed and low wind speed regions. Under these operating conditions, hybrid turbine possesses better performance than straight-bladed turbine

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