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Aerodynamic Performance Improvement of Hybrid Darrieus-Savonius Vertical Axis Wind Turbine

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ABSTRACT: Returning blades of Savonius vertical axis wind turbines make negative effects on the total moment produced by the turbines especially at high tip speed ratios. For hybrid Darrieus-Savonius vertical-axis wind turbines at the dynamic mode, with tip speed ratio increment from self-starting to that of high values, returning blades of its Savonius part make the whole part to produce negative moment. In the present work, in order to reduce negative effects of returning blades of Savonius vertical-axis wind turbines and consequently improve its aerodynamic performance, a wall is placed in front of them. Several configurations including two types of blade shapes with three types of wall placements are simulated three-dimensionally and their output-moment and moment fluctuations are computed for one complete cycle. Desired Savonius vertical-axis wind turbine with suitable wall which produces the most average-moment and the least moment fluctuations are mounted on a straight-blade Darrieus vertical-axis wind turbine and they formed a hybrid vertical-axis wind turbine. In comparison to straight-blade vertical-axis wind turbine, at the tip speed ratio of 0.9 proposed hybrid vertical-axis wind turbines produces 2.3% more average-moment along with 40% fewer moment fluctuations. This means in term of tip speed ratio values, proposed hybrid vertical-axis wind turbine has wider operating range in comparison to its general types.

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1. INTRODUCTION

Straight-blade Darrieus Vertical-Axis Wind Turbines (VAWTs) suffer from self-starting problem [1]. Many researchers propose hybrid turbine VAWTs which combine Savonius and Darrieus VAWTs together in order to increase their start-up moment. Although this configuration improves the self-starting performance of the turbine, Savonius part of the hybrid turbine reduces the total moment produced by the whole turbine at high tip speed ratios (TSRs) [2, 3].

In the present numerical simulation, in order to reduce the negative effects of returning blades of Savonius VAWTs and consequently improve its aerodynamic performance, a wall is placed in front of them. Desired Savonius VAWT with suitable wall which produces the most average-moment and the least moment fluctuations are mounted on a straight-blade Darrieus VAWT and they formed a hybrid VAWT.

2. GOVERNING EQUATIONS AND NUMERICAL MODELING

Transient three-dimensional incompressible turbulent flow is simulated using the sliding mesh technique by the solution of RANS[1] equations with finite volume method. Using recommendations of most researchers, turbulence model $k-w\ SST$ is utilized.

3. TURBINES GEOMETRY

Generally, two shapes of Savonius blade (Types 1 and 2) with three types of wall placement (Types *A*, *B,* and *C*) are simulated. Wall of type *A* is located in the line of turbine center and type *C* has 0.3 m distance from that.

Turbines rotate in the positive direction of *Z*-axis. The azimuth angle is defined in the *X-Y* plane and is set equal to zero on the *Y*-axis. At each cycle of the turbine, azimuth angle increases from 0° to 360°, counterclockwise. Figs. 1 and 2 show geometrical specifications of turbines *B1* and *B2* while

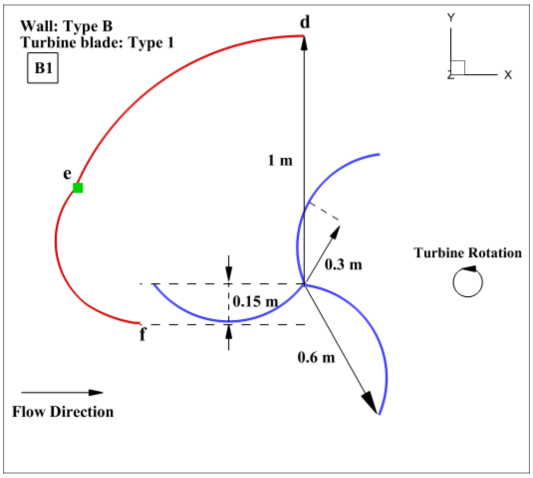

Fig. 1. Savonius turbine of *B1*.

1 Reynolds Averaged Navier-Stokes

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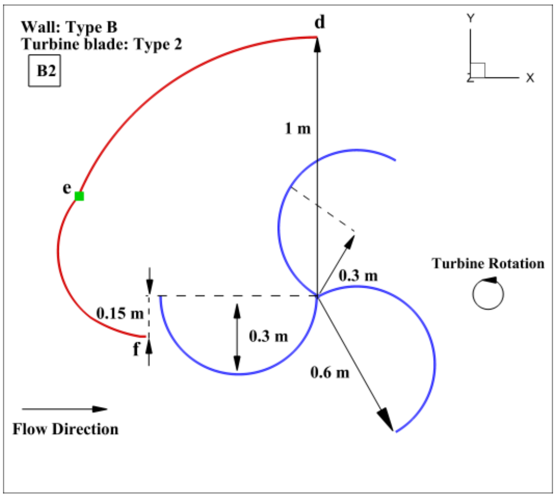

Fig. 2. Savonius turbine of *B2*.

their second blades are located at azimuth angle of 90°. The maximum radius of wall is equal to R=1 m and its height is equal to Savonius blades, 0.4 m.

4. COMPUTATIONAL DOMAIN AND GRID GENERATION

As shown in Figs. 3 and 4, solution domain is a rectangular cube, including stationery and rotating zones. Constant free stream velocity of 7 m/s along X-axis and static pressure at sea level condition of standard atmosphere have been applied at the inflow and outflow boundaries, respectively. Unstructured grid with about 5.3e+6 control volumes is generated within the domain, except close to the turbine blades, the wall and over the rotating zone where structured grid is generated.

5. VALIDATION

The experimental data of Elkhoury et al [4] and Fujisawa [5] are used to validate present simulation results for Darrieus and Savonius turbines, respectively. As shown in Fig. 5 according to total errors of less than 4%, good agreement is obtained.

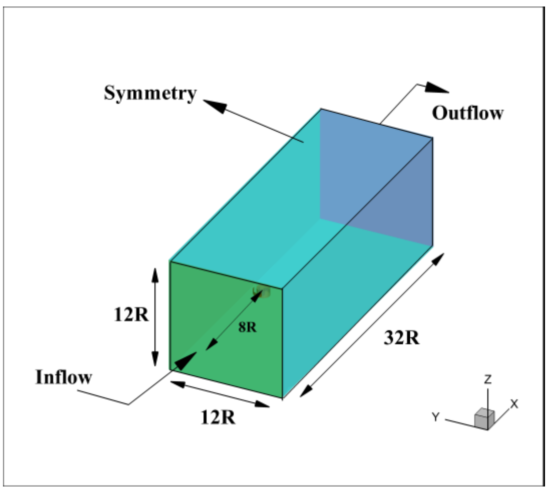

Fig. 3. The computation domain.

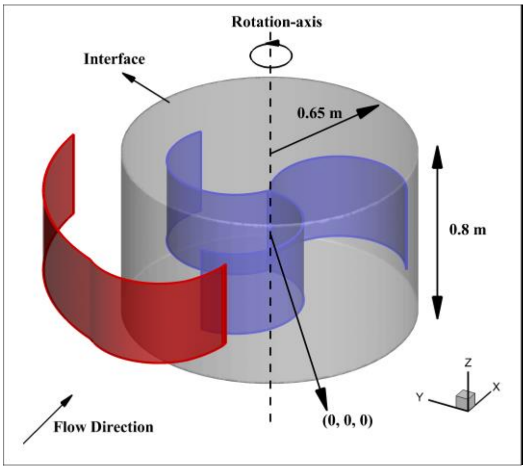

Fig. 4. The rotating zone and wall.

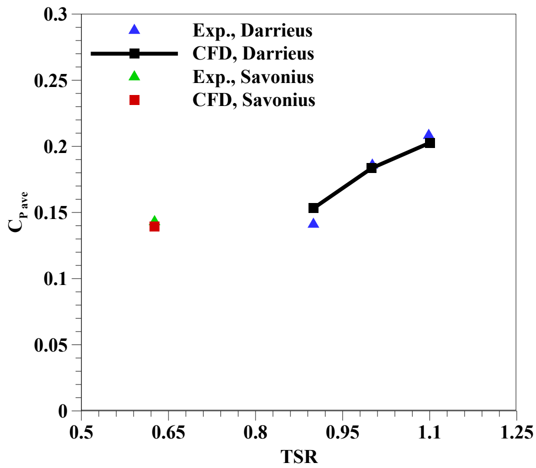

Fig. 5. Validation of the present simulation using Refs. [4, 5].

6. RESULTS AND DISCUSSION

After investigation of the total moment produces by each of the six cases of turbines and walls, the important results are presented. As seen in Fig. 6, the wall clearly has improved

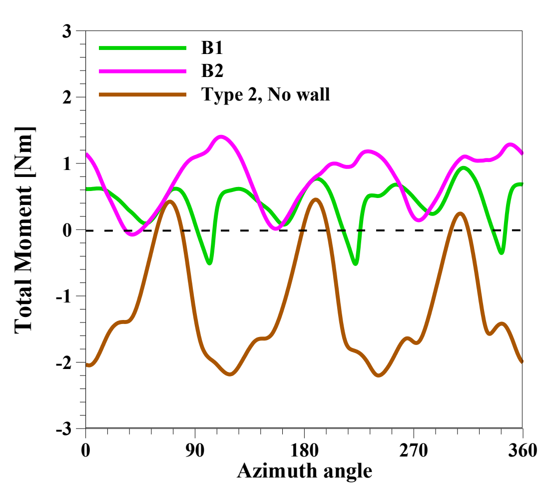

Fig. 6. Savonius turbines of *B1* and *B2* at 60 rpm.

total moment produced by Savonius turbine at 60 rpm. This means using proper wall has been made this rotational speed to come into the performance range of the turbine. In comparison to no wall type, configuration of *B2* has better performance with 164% more average of total moment and 48% less total moment fluctuations.

To perform smoother in terms of the total moment, an overlap of 0.1 m for turbine blades of *B2* is selected, according to Fig. 7. Results show that the overlap makes turbine *B4* to produce 2.6% more average of total moment with 40% less total moment fluctuations.

According to results of Fig. 8, turbine of *B4* produces 222% more average of total moment with 48% less total moment fluctuations. This turbine is chosen for Savonius part of hybrid turbine. As seen in Fig. 9, Savonius turbine of *B4* is mounted on a three-blade straight Darrieus VAWT with the same radius of Savonius part and height of 1.15 m. NACA0021 airfoil section with chord length of 0.3 m is selected for straight blades. As about the TSR, 60 rpm is equivalent of 0.9.

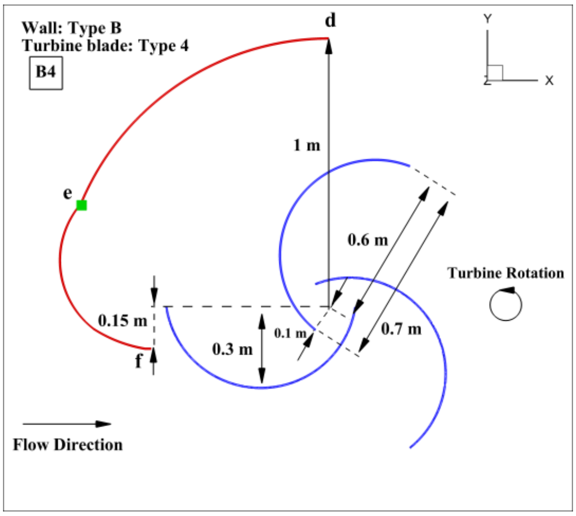

Fig. 7. Savonius turbine of *B4*.

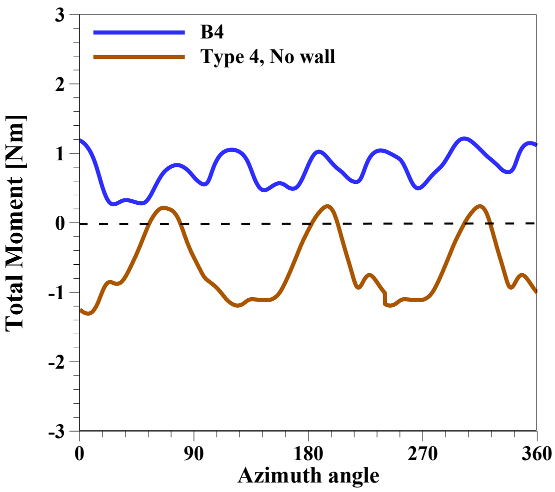

Fig. 8. Savonius turbine of *B4* at 60 rpm.

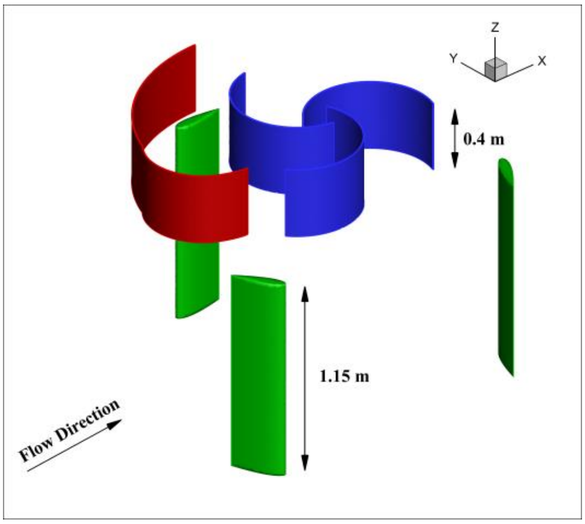

Fig. 9. Proposed hybrid turbine.

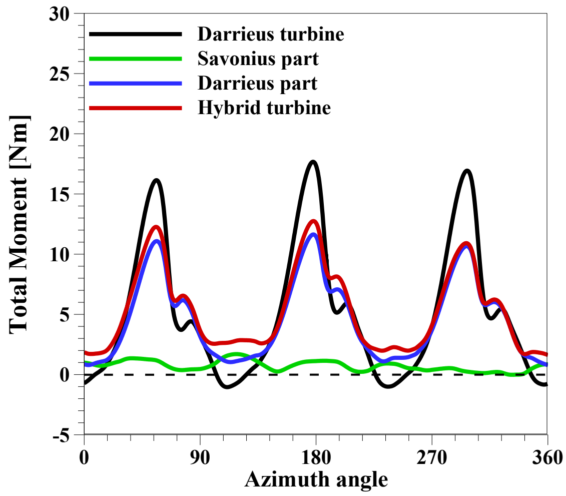

Fig. 10. Comparison of the straight-blade VAWT and proposed hybrid turbine at 60 rpm.

The total moment produced by the proposed hybrid VAWT is compared with a three-blade straight Darrieus VAWT with the same radius and height (1 m and 1.6 m respectively) at mentioned TSR. According to results of Fig. 10, at the TSR of 0.9, the hybrid turbine produces 2.3% more average of total moment with 40% less total moment fluctuations.

7. CONCLUSION

Using the proper wall and Savonius blades, make the whole hybrid turbine to still work in TSR values around 0.9 and this is the high limitation of performance range of the hybrid turbine without any negative effects from Savonius part. Clearly according to results, conventional hybrid turbines cannot perform in aerodynamic performance as good as the proposed turbine.

As about the wind direction-dependent of the hybrid turbine, this can be simply solved using a simple blade to work as a vertical stabilizer.

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