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RESEARCH ARTICLE

A NUMERICAL STUDY OF THE TURBULENCE MODEL INFLUENCE ON A SAVONIUS WIND TURBINE PERFORMANCE BY MEANS OF MOVING MESH

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ABSTRACT

This numerical research has investigated the influence of the turbulence model on a Savonius wind turbine performance. The numerical simulation has been applied by using two-dimensional analysis of Computational Fluid Dynamics through moving mesh technique to solve the incompressible Unsteady Reynolds Averaged Navier-Stokes equations. In this study, the turbulence model has used RNG k-epsilon, standard k- epsilon, Realizable k-epsilon, SST k-omega, standard k- omega, and spalart-allmaras. Firstly, the numerical model has been verified by the experimental data towards the torque coefficient at a tip speed ratio (TSR) of 1.078 and has used the Realizable k-epsilon (RKE). Then the turbulence models are compared with experimental data towards torque coefficient at TSR change. The verification has been achieved and compared to the turbulence model variations. The results of numerical simulation reveal that Realizable k-ε (RKE) has the performance approach of experimental data within the Cp Error about 1.67% at TSR of 0.9.

KEYWORDS

Savonius vertical axis turbine, moving mesh, turbulence model, realizable k-epsilon, performance.

1. INTRODUCTION

The notion of improving Savonius wind turbine performance is becoming an important issue for current researches. Both vertical and horizontal axis wind turbines are worthy of notice, particularly the vertical axis water turbine. Due to its performance doesn't depend on wind direction and its benefit to produce the small scale power [1]. The previous numerical and experimental studies on the Savonius turbine have provided fascinating insights. The experimental study on wind tunnel of Savonius turbine has been carried out at the wind speed of 7 m/s by varying the number of buckets and the overlap ratio. The bucket number is varied between 2 and 3 buckets, thus the best performance is revealed through the 2 bucket number. In addition, the overlap ratio is varied from 0.0 to 2.0 and the best performance is obtained at the 0.1-0.15 overlap ratio [2]. This study uses those data for verification and validation at a wind speed of 7 m/s. Moreover, the next research on the overlap ratio also has been conducted by using numerical simulation on the Savonius torque which has been obtained at the overlap ratio of 0.2 [3]. The problem of numerical uncertainty has been carried out by producing the policy. This research will support the policy to improve the accuracy of numerical results which numerically used second-order upwind, grid independence or convergence, iterative convergence must be addressed, numerical usage of transient calculation which must be compared with the experimental results, inherent or explicit artificial viscosity usage of turbulence model variations [2,4]. A numerical study has also been conducted by using the turbulence model of RNG k-epsilon. The modified Savonius usage of myring equation variation has been applied within a y^+ range from 30 to 100. The validation has been compared to the experimental data and the maximum Cp has been obtained at n of 1 [2,5]. The turbulence model for k- epsilon also has been investigated by comparing RNG k-ε to standard k- epsilon. The best results show that the standard k- epsilon (SKE) having the value of Cp approach on the experimental data [6]. The modified Savonius has been studied by placing a cylinder at the advancing side to obtain the best performance at ds/D of 0.7 [7]. Another research has been carried out by varying cylinder diameter at each stagger angle and the maximum performance has been gained at ds/D of 0.5 for stagger angle 30° and 60° [8]. Several researchers have performed the numerical study on 2D simulation for a Savonius turbine which revealed that 2D simulations produce more effective results [9-13].

From this background of knowledge, this research is intended to apply only y^+ range between 30 and 100 for all turbulence models [5]. In order to know the influence of y^+ value towards the Savonius performance and error of the power coefficient, all of the turbulence models will use y^+ value at this condition to solve the problem. The statement shows that the ten policy is really essential to generate post-processing in ANSYS 17.0 well. One of the policy i.e. the numerical analysis result must compare among the turbulence model will be adopted in this study [4]. Based on the guideline of ANSYS 17.0, correlation of the y^+ value and the turbulence model will influence post-processing result. This is directed to determine the proper turbulence model and the y^+ value in range 30 – 100 towards the Savonius wind turbine performance. This paper concerns to the turbulence model influence on Savonius wind turbine performance by varying the turbulence model namely RNG k-epsilon, standard k- epsilon, Realizable k- epsilon, SST k-omega, standard k-omega, and spalart-allmaras. The coefficient of performance will be compared with the published experimental data [2].

2. PROBLEM STATEMENT

Each researcher usually recommends the other next researchers to select the turbulence model directly without comparing the turbulence model variations. The prediction of performance results always uses one of the turbulence models to solve the problem and never investigate the changing of turbulence model from the ten policies [4]. This case, the Savonius turbine is relevant to the turbulence model regarding the value of y^+. The guideline of ANSYS 17.0 shows that y^+ value will influence the numerical results [14]. It is crucial to clarify the results by the usage of changing turbulence model for the y^+ value between 30 and 100. In this y^+ value, this study will investigate the turbulence model influence on the performance of the Savonius turbine. In this case, boundary conditions use symmetry to avoid the wall influence on the upper side and lower side. On other hands, this work will be done no blockage ratio by using symmetry in the wall at boundary condition.

3. DIVERSITY OF TURBULENCE MODEL

The diversity of the turbulence model in this paper will be discussed deliberately focusing on various turbulence model such as spalart-allmaras, k-epsilon, and k-ω explained as follow;

3.1 Spalart-Allmaras Turbulence Model

Spalart-Allmaras is the RANS model with a low-cost for a modified eddy viscosity to solve the equation of a transport. The modified form is applied for the eddy viscosity close to the wall in order to resolve easily. The application in this turbulence model can be used for aerodynamic or turbo machinery, such as the flow of supersonic or transonic over the airfoils, the flow of boundary-layer, and etc. This turbulence model is one-equation models and the calculation of a length scale is not necessary due to the thickness of the local shear layer. Specific design for the application of aerospace includes wall-bounded flows. It has been shown to provide better results for boundary layers subjected to adverse pressure gradients. The application of turbo machinery is very popular although it can be said relatively new. There is no claim to make prompting on the application for all types of complex flows.

3.2 The k–epsilon Turbulence Model

3.2.1 Standard k– epsilon (SKE) turbulence model.

The application mostly used in industry is the type of this turbulence model that can be said more reasonable and robust accurate. The turbulence model can be applied for combustion, buoyancy, compressibility. The epsilon (ε) equation has the limitation that cannot calculate at wall, however, the equation needs wall function. The turbulence model has generally poor performance for the large gradient of pressure, streamline and the strong separation.

3.2.2 Renormalization group (RNG) k– epsilon turbulence model.

Renormalization group is the result of deriving the k–ε equations. The model of differential viscosity is used to explain the low Reynolds. The algebraic formula is derived analytically from turbulent Prandtl or Schmidt number and swirl modification. The RNG turbulence has better performance than SKE for more flows of complex shear, flows with swirl, and separation.

3.2.3 Realizable k– epsilon (RKE) model.

The term of the realizable turbulence model fulfills certain mathematical constraints on the stresses of Reynolds with the turbulent physics flows. Realizable turbulence model is more accurate to predict the spreading rate of both round and planar jets. This turbulence model has superior performance for flows involving recirculation, rotation, separation and boundary layers with strong adverse pressure gradients.

3.3 The k–omega Turbulence Models

3.3.1 Standard k–omega (SKW)

In the turbo-machinery communities and the aerospace adopt Standard k–omega such as transitional flows, shear-flow, and compressibility effects.

3.3.2 Shear Stress Transport k–omega (SSTKW) model (Menter, 1994).

The formulation of modified turbulent viscosity is used to calculate the effects of transport from shear stress of the principal turbulent.

4. NUMERICAL METHODS

In this study, the Savonius turbine uses dimension with turbine diameter (D) of 1 m, free stream velocity (U) of 7 m/s and the Reynolds value of 4.32. 10^5 [2]. The turbulence model is varied among RNG k-epsilon, standard k-epsilon, Realizable k-epsilon, SST k-omega, standard k-omega, and spalart-allmaras. Savonius rotor rotation can be shown in Figure 1. Boundary conditions can be seen in Figure 2 as follow;

- Inlet functions as velocity inlet with 10D from the center of Savonius turbine.
- Outlet functions as a pressure outlet at 10D from the center of Savonius turbine.
- The upper side and lower side of the flow domain function as symmetry and taken at 6D from the center of Savonius turbine.
- Savonius turbine is in rotating zone.

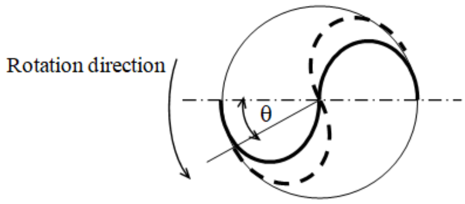


Figure 1 : Savonius rotor rotation

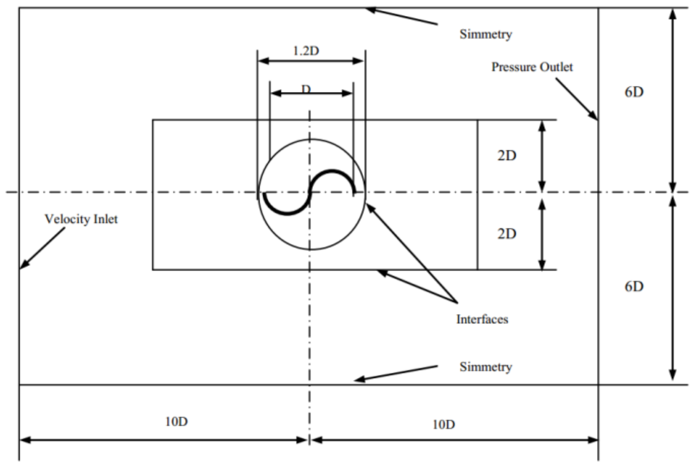
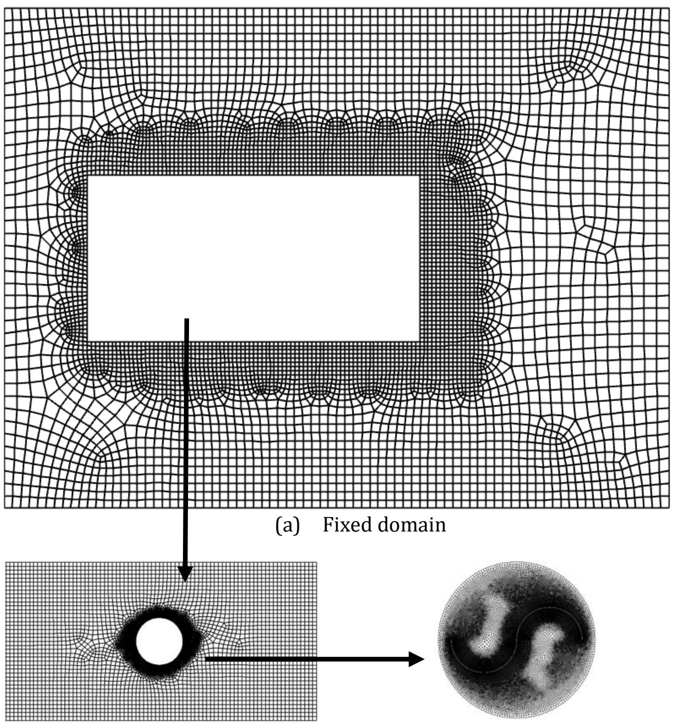


Figure 2: Boundary conditions of the model

Boundary conditions have three domains as depicted in Figure 3. The computation from geometry to meshing is generated by using the tool in Gambit 2.2.30 and then running in ANSYS 17.0 using 2D. The meshing size is carried out for setting the y^+ value near wall of the first elements between 30 and 100, depending on turbine rotation and the position of the element on the blade as shown in Figure 3 [5].



(a) Fixed domain

(b) Wake domain (c) Rotating domain

Figure 3: Mesh generation

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Firstly, verification performed and compared to the experimental analysis with torque coefficient at Reynolds number of $4.32.10^5$ [2]. The simulation verification changes grid size from the coarse level to fine at TSR of 1.078 as depicted in Table 1. The grid sizes are 17,006, 61,105 and 120,000 nodes. The numerical simulation uses boundary condition as demonstrated in Figure. 2. The verification results can be perceived in Figure 4 by varying the node number by taking data of torque coefficient as the function of blade rotation (θ). The used turbulence model is the Realizable k-epsilon with the enhanced wall treatment. The results curve in Figure 4 has shown that the number of nodes 61,105 and 120,000 nodes are almost the same. Thus, the next process will use the nodes number of 61,105 to increase time efficiency while all of the turbulence model variations use this node.

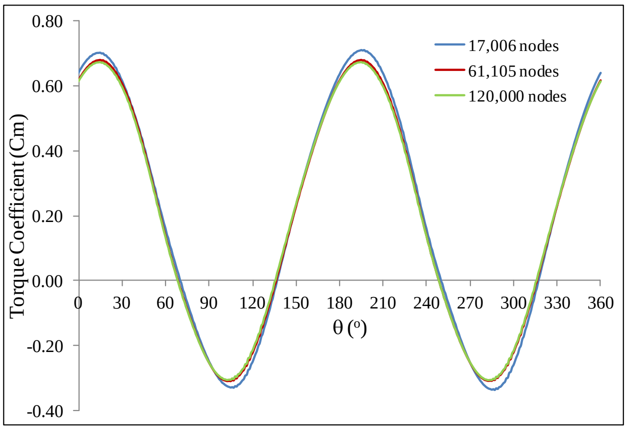

Figure 4: Verification with nodes variations

The experimental study has been conducted in the wind tunnel by Sheldahl and his group using a velocity 7 m/s and 14 m/s [2]. This present study will be performed for velocity of 7 m/s. Thus, the verification and validation results can be demonstrated in Table 1. The size of the turbine is 1 m of diameter and 1 m of height. The next step has been done by varying to the turbulence model using data as presented in Table 2.

Table 1: Data of verification [2]

TSR	N (RPM)	ω (rad/s)	NTS (s)	TSS (s)
1.078	144.087	15.095	51,871	0.0011627

Table 2: Data input by varying the turbulence model

TSR	N (RPM)	ω (rad/s)	NTS (s)	TSS (s)
0.3	40.091	4.200	14,433	0.00415567
0.5	66.818	7.000	24,055	0.00249340
0.7	93.545	9.800	33,676	0.00178100
0.9	120.273	12.600	43,298	0.00138522
1.1	147.000	15.400	52,920	0.00113337
1.3	173.727	18.200	62,542	0.00095900

5. RESULT AND DISCUSSIONS

5.1 Torque coefficient (Cm) and power coefficient (Cp)

The parameters of the Savonius turbine included the value of torque coefficient (C_m) and power coefficient (C_p). The power coefficient of Savonius can be called as the performance Savonius. The coefficient of torque is exposed in Figure 5 and Figure 6 in accordance with the change of the turbulence model. Numerical simulation has been conducted by changing the turbulence in order to find out the influence of the torque coefficient at the Savonius turbine.

The coefficient of power based on the tip speed ratio (TSR) can be seen in Figure 6. The red line is trendline for published experimental data [2]. The curve shows that maximum power occurred at TSR of 0.9 for spalart allmaras and Realizable k-epsilon but the other turbulence models occurred at TSR of 0.7.

The coefficient of power demonstrates the difference in simulated results, while it is recognized with some error or uncertainty results proceed to all turbulence model implemented for 61,105 nodes with y^+ value in about 52. The curve in Figure 6 can be seen as the highest error occurs at standard k-epsilon for all tip speed ratio (TSR), which is the standard k-epsilon shows under prediction compared with other turbulence models. The similar result occurred at SST k-omega and RNG k-epsilon with over prediction compared other the turbulence model despite the error of RNG k-epsilon is less than SST k-omega at the tip speed ratio (TSR) from 0.7 to 1.3. Other turbulence model indicated a similar curve. The Spallart Almaras exposed over prediction at TSR from 0.7 to 1.3 and the realizable k-epsilon occurred over prediction from 1.0 to 1.3. The most effective power coefficient of turbulence model variation occurred at the realizable k-epsilon, which are curve similar based on the published experimental data [2]. The realizable k-epsilon turbulence model indicated over prediction due to the Savonius turbine simulation by means of 2D simulation. The usage of 2D simulation reveals that there is no end plate, turbine shaft at Savonius turbine.

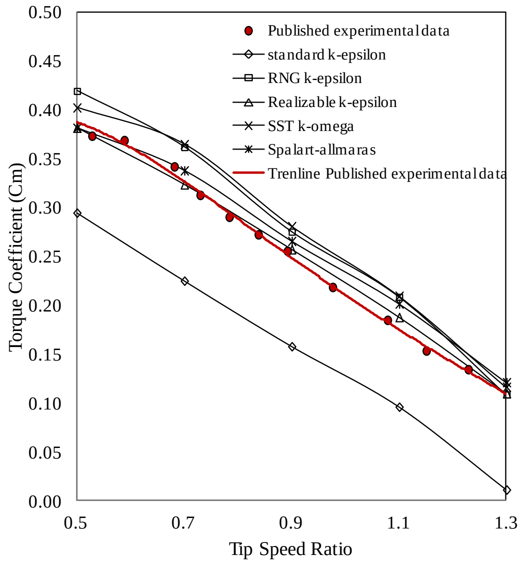

Figure 5: The performance of the Savonius turbine for Torque Coefficient (Cm) within turbulence model change.

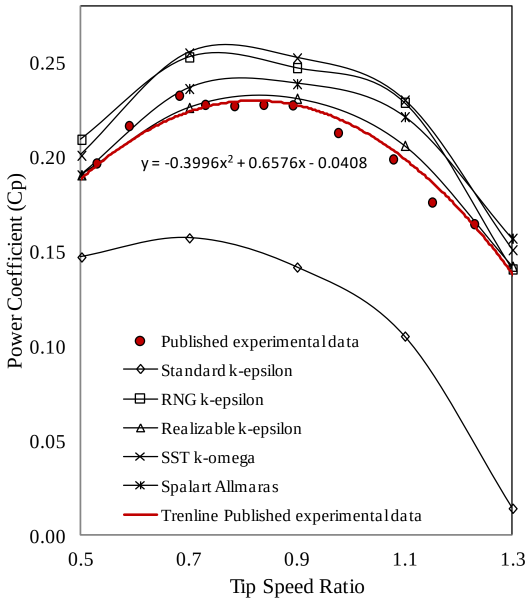

Figure 6: The performance of the Savonius turbine for power coefficient (Cp) within turbulence model change

5.2 Power coefficient Error (%)

The power coefficient is called the performance coefficient and made graph Cp error in % as shown in Figure 7. The calculation of error (%) will be used to compare each the turbulence model. High Cp Error indicates the high deviation towards the experimental data. The assumption of this study uses symmetry on the upper side and lower side. The channel assumption does not influence the performance turbine. Meanwhile, the blockage ratio is too large in experiment channel. The results reveal that the best performance in simulation is Realizable k-epsilon (RKE) because of the similar curve towards the experimental data and low Cp error. Based on the y^+ value about 52 indicating that the y^+ value is relevant to the turbulence model. From strategy in ANSYS, the y^+ value needs more iteration using SST k-omega by decreasing the y^+ value until 1 for low Cp error.

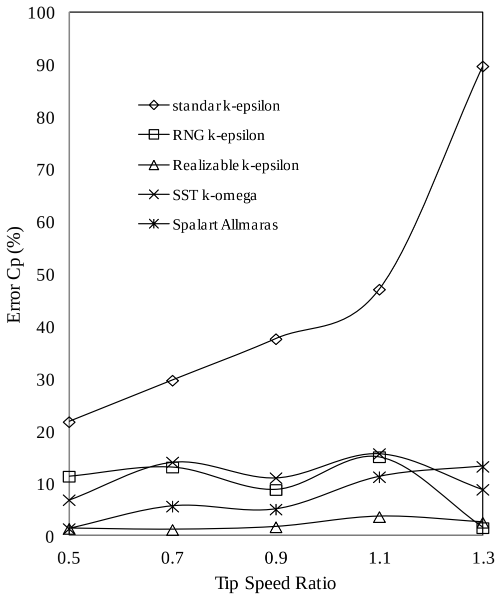

Figure 7: Error Cp (%) with tip speed ratio

The results of Cp error (%) as the function of tip speed ratio (TSR) with the turbulence model variations have demonstrated in Figure 7. The Cp error (%) of Standard k-epsilon increases by increasing the tip speed ratio (TSR) with highest Cp error. Cp Error value decrease at SST k-omega and RNG k-epsilon. The turbulence model having low error Cp is Spalart Allmaras and Realizable k-epsilon. The results of numerical simulation, which cannot eliminate error (%) but it is still able to decrease error (%) has approximately the same results as the published experimental data. The results of the turbulence model variations also reveal that the Realizable k-epsilon are similar to the published experimental data with Cp Error about 1.67% at TSR of 0.9 [2].

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the above result discussion, some points can be highlighted as the conclusion:

1. The Realizable k-epsilon has approximately the same curve as the experimental data for torque coefficient and power coefficient.
2. The turbulence model of Realizable k-epsilon (RKE) has low Cp Error in about 1.67% at TSR of 0.9.

6.2 Recommendation

The recommendations for future research should be performed by changing the y^+ value within the turbulence model variations less than 1 in order to discover which turbulence model is appropriate for the y^+ value variations. Each of the turbulence models has the range of y^+ value and depends on the reliability of the personal computer. The strategy from ANSYS 17.0 recommends the suggestion for varying the y^+ value range from the coarse level to fine.

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