Numerical Investigation on Work Performance of Tocardo-type Turbine Using BEM Method

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Abstract: In this paper, work performance of Tocardo-type turbine is numerically investigated by using BEM method. Tocardo-type turbine is significantly different from lift-type turbine in which it owns long chord and thick blade and it is of bidirectional characteristics. Working performance of Tocardo-type turbine is obtained by using BEM method and the results release that it is not of lift-type turbine because the parameter of Cl/Cd is not chosen as maximum value. Compared with the performance of lift-type turbine, working coefficient of Tocardo-type turbine is little lower at optimum working condition. The results also show that the optimized tip speed ratio of Tocardo-type turbine is about 4.5 and working power reaches about 183kW as coming velocity is 4m/s.

1. Introduction
Energy is an important driver of economy. However, energy demand pressure, now, is coming more and heavier, the researchers start to study renewable energy gradually. In the new energy sector, tidal current energy has achieved significantly economic interests. Now, many countries are all raising tidal current projects supported by governments and companies [1]. In different kinds of turbines, horizontal current turbine is popular because of its high efficiency, big self-starting torque etc., compared to other kind turbines. [2]

BEM[3] is most classical theory among those methods and widely used to analyze dynamics of wind turbine and current turbine. BEM theory assumes fluid pressures are equal between front and rear of wind rotor, so it ignore blade pressure reduction generated by trailing vortex, which leads to relatively large differences between test results and calculated results of BEM theory about wind turbine. Joukowsky improved BEM method in the situations of low tip speed ratio (TSR) through considering trailing vortex [4]. Micallef et al. did CFD simulation for solving a problem that BEM theory ignores kinetic momentum generated by tangential velocity. That work provided a few of fundamental insights and experimentally and numerically confirmed that radial flows reach appreciable magnitudes especially in the tip region [5]. Fluid motion, in the tip of blade, is extremely complex because of not only tangential motion but also turbulence flow. In the BEM computations, airfoil data are corrected for three-dimensional and rotational effects. However, such corrections are of another nature than what is needed near the tip, where the flow is largely attached and rotational effects are negligible. In order to include three-dimensional tip loss effects, Shen et al. suggested to compute the resulting force coefficients in equations [6]. Khchine combines new tip loss correction and new axial flow induction...
factor to optimize blade geometry based on Shen’s method[7].

In this paper, we extend scope of BEM applications to study a non-lift-type turbine based on the conservations of momentum and angle momentum. One company have invented a new turbine called Tocardo-type turbine owing long chord and thick blade, which the geometry of the turbine is significantly different from traditional lift-type turbine designed by BEM. In the beginning, this paper introduces BEM and come up with a new form of BEM analysis Tocardo-type turbine. Next, various characteristic of Tocardo-type turbine are analyzed compared to lift-type turbine.

2. Blade elements momentum theory

2.1 The computational process and characters of lift-type turbine

BEM split blade to several elements for simulating two dimensional fluid motion based on assumption that adjacent blade elements make no influence and two dimensional fluid homogeneity flowing through blade element. As far as the horizontal current turbine, fluid has two flow modes that one is flowing along the horizontal axis and another is circular motion opposite to the direction of blade rotation. Considering momentum loss in axial and tangential motion, axial flow induction factor (a) and tangential flow induction factor (a’) are introduced to compute axial and tangential velocity for analyzing blade element output power. Finally, whole rotor output states equal to total all elements power.

![Flow chart of BEM for lift-type turbine](image1)

**Figure 1.** The flow chart of BEM for lift-type turbine

Essentially, the calculation of current turbine performance is continual convergent process of the axial and tangential flow induction factor. The process is plotted in figure 1. In the flow chart, λ is tip speed ratio, R is radius, N is numbers of blade, α is angle of attack, C is chord, Φ is angle from fluid velocity to the plane of rotation.

At the same time, it is necessary that one blade element’s a and a’ are iteratively calculated after chord is found based on the assumption of optimal a and a’. According to Reynolds number computed by assumed a and a’, a serious of Cl and Cd are computed in different angle of attack. Maximum Cl or Cl/Cd is selected from various Cl and Cd to obtain new a and a’. The process is repeating until convergent solutions are found. The lift-type turbine with small chords and refined blade, designed by using traditional form of BEM, can generate high lift and high power because maximum Cl or Cl/Cd is selected.

2.2 The computational process and characters of Tocardo-type turbine

Under the condition of giving chord distribution, the treatment with maximum Cl/Cd does not valid any
more for the solution of \( a \) and \( a' \) in the BEM application of Tocardo-type turbine. The possible reason causing misconvergence of \( a \) and \( a' \) is seeking for then. Firstly, longer chord distribution of Tocardo-type turbine along with radial direction is discussed. Bigger chord may directly affect Reynolds number of each blade element, which may result in the misconvergence of \( a \) and \( a' \). In this paper, changing original optimization objective of searching maximum \( Cl/Cd \) to minimum \( (a-a0) \) and \( (a'-a'0) \) is implemented. The process of this new treatment is shown in figure 2.

Comparing with traditional BEM, the new method proposed in this paper for Tocardo-type turbine still obeys the basic conservations of momentum and angle momentum, only optimization objective is different. General speaking, the treatment is valid for any chord length during the solution of \( a \) and \( a' \) in which the calculation of \( a \) and \( a' \) for chord distribution of lift-type turbine is one specified case.

3. Analyze of Tocardo-type turbine based on BEM

3.1 Geometry comparison between Tocardo-type turbine and lift-type turbine

The blade geometry of Tocardo-type turbine and lift-type turbine are obviously different shown in figures 3 and 4. Tocardo-type turbine blade is more bigger and fatter than that of lift-type turbine. The quantitative differences of chord and angle of attack are illustrated in figures 5, 6.

![Figure 3. Geometry of Tocardo-type turbine](image)

![Figure 4. Geometry of lift-type turbine](image)

Figure 5 shows that the chord of Tocardo-type turbine chord is significantly longer than that of lift-type turbine and the chord, in middle part of Tocardo-type turbine blade, is slightly changed while the chord changed rapidly in the location of tip and root. In addition, the distributions of twist angle for two kind of turbine are plotted in figure 6. It is clearly that all twist angle of blade of Tocardo-type turbine is bigger than that of lift-type turbine. Those data including chord distributions and twist angles is line drawn based on the picture from Tocardo company websites.

![Figure 5. Blade geometry parameters of Tocardo-type turbine and lift-type turbine](image)

![Figure 6. Twist Angle distributions of Tocardo-type turbine and lift-type turbine](image)

3.2 Selection of Airfoils

Different series airfoils are studied for analyzing its influence of Tocardo-type turbine before further investigation. Three low-Reynolds number airfoils, S805A, ClarkV and NACA63210, respectively are chosen shown in figure 7. Under same coming velocity, 4m/s, tip speed ratio, 6 and radius, 2.15m, the proposed BEM treatment is implemented to design turbines based on three different airfoils.

Figure 8 shows the solutions by using the proposed BEM treatment. The results illustrate that airfoils have little influence on turbine power but serious influence on turbines’ twist angle. Among those turbines, S805A is fit for Tocardo-type turbine since twist angle of S805A is smaller and blade is thicker. Therefore, S805A is taken as basic airfoil in later work of this paper.
3.3 The Performance Analysis between Tocardo-type turbine and lift-type Turbine

Work performance of Tocardo-type turbine is computed by using the proposed BEM treatment. All the results have been obtained at the conditions of incoming velocity, 4 m/s, tip speed ratio, 6. Tip and root loss corrections are included in the process of analysis.

The calculated working power results of Tocardo-type turbine are plotted in figure 9. Figure 9 shows that the power of Tocardo-type turbine declines as TSR raising from 5 to 7. Moreover, the power of Tocardo-type turbine gradually increases with TSR from 3.5 to 4.5 and reaches to maximum efficiency as TSR is equal to 4.5.

Figures 10-12 shows the power comparisons between Tocardo-type turbine and lift-type turbine as TSR is 3.5, 4.5 and 5.5. The results indicate that the output power of lift-type turbine is larger than that of Tocardo-type turbine. The more power results are summarized in the figure 13. Among those TSRs, 4.5 is found optimized TSR and the power of Tocardo-type turbine at that TSR is about 183kW and the corresponding working coefficient is about 39.5%. The power of lift-type turbine is higher than that of Tocardo-type turbine except for the case that TSR equals to 3.5. In addition, the difference becomes more and more larger as TSR raising from 4 to 7. The reason for the difference between two kinds turbines is explained that the blade of Tocardo-type turbine with longer chord losses the optimum working condition of airfoil and then causes the reduction of efficiency.
In this paper, Tocardo-type turbine and lift-type Turbine, Cl and Cd, corresponding convergent a and a', are selected to further study based on same conditions: incoming velocity is 4m/s, TSR is 4.5, radius is 2.15m. The distributions of Cl/Cd shown in figure 14 and 15.

Figure 14 and 15 show that Cl/Cd of different blade elements of lift-type turbine are equal and located in maximum value when a and a’ are convergent. In contrast, the values of Cl/Cd are not equal to the maximum value in the design of Tocardo-type turbine. The values of Cl/Cd for Tocardo-type turbine gradually decrease as r/R raising from 0.28 to 0.87. Cl/Cd of lift-type turbine always higher than Tocardo-type turbine which is believed the reason that lift-type turbine gives better output power than Tocardo-type turbine. At the same time, the conclusion could be drawn that Tocardo-type turbine is not lift-type turbine.

At last, the reason how the values of Cl/Cd influent turbines’ power is analyzed. The distributions of a between Tocardo-type turbine and lift-type turbine are drawn in figure 16. The values of a for Tocardo-type turbine is more and more higher than that of lift-type turbine as r/R raising. The phenomenon is believed due to the difference Cl/Cd between two type turbines. Since larger value of a implies smaller incoming kinetic energy to be converted by turbine, the power of Tocardo-type turbine decreases.

4. Conclusion
In this paper, the Tocardo-type turbine has been calculated and analyzed by using BEM. The results are compared with that of lift-type turbine and are analyzed in detailed. The following remarks are addressed:
1. The Tocardo-type turbine is not lift-type turbine.
2. Different airfoils have a little influence on output power of Tocardo-type turbine.
3. Working efficiency of Tocardo-type turbine is about 39.5% as TSR equal to 4.5 and output power is about 183kW. The output power is little lower than that value of lift-type turbine at optimum working condition.

Reference

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