Study on the performance and optimization on the mesh skewness of the Savonius wind turbine resembling lotus in shape

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Abstract: The Savonius wind turbine is the most suitable type for the low wind speed condition and low power applications. The many computational method was conducted in order to predict its strengths and weaknesses of each wind turbine type. Using numerical prediction on the performance of wind turbine give us the extreme benefit over the classical experimental techniques, the major benefit of computational studies is more economical than doing the experiment and avoiding the human errors. In the present paper, a new blade shape of the Savonius wind turbine resembling lotus in shape was designed as a garniture for the building and street lighting systems. The Savonius rotor has been explored in order to emulate lotus in appearance. Furthermore, the appropriate mathematical technique called "renormalization group" (RNG) method was used to define the performance of Savonius wind turbine resembling lotus in shape, and the direct optimization was employed to minimize the mesh skewness. Results showed that with the new blade shape of Savonius wind turbine resembling lotus in shape, it has a high power coefficient and good at self-starting after employing the suitable turbulence model. Moreover, from the optimum result, showed that by using the direct optimization, the minimum of the skewness is automatically defined.

Key Words: Savonius wind turbine resembling lotus in shape; Torque Measurement; Turbulence Model; Direct Optimization; Computational Fluid Dynamic; Savonius Rotor.

1. INTRODUCTION

In the recent years, reduce the environmental impact and over fuel consumption have been gaining more interest. These reasons lead to grow the study concern with the environmental issues and the energy fields. Many researchers have tried to find the renewable energy sources that have less affect to the environment and produce the effective energy. Following this line, a new blade shape of Savonius wind turbine was designed: the main idea that leads to design a new blade is to develop a system that can locate along the street and in the building; especially, to reduce the visual impact of the people. The choice that lead to use the new blade shape of a Savonius wind rotor because of many reasons: it is easy to build, low sound pollution, economic, and it can make the building or public area look more beautiful due to it was built to make it looks like a flower or lotus for its appearance. Moreover, it is a suitable type for the turbulent velocity, higher static torque (auto-starting wind turbine), and easy to repair. However, its efficiency is naturally low if compared to the conventional wind rotor (Manet et al, 2001; Chen et al, 2012). Hence, the improvement about the characteristic of Savonius wind rotors using experimental, theoretical or numerical methods was applied by many authors.

Hayashi et al (2005) tested a wind tunnel experiment using single and three stages Savonius rotor. The static torque of the three stages winds rotor was increased and decreased the fluctuation, yet its dynamic torque has a lower value than the single stage. The most recent experiments about the Savonius system was studied by Irabu et al, in 2007 using a guide box tunnel to enhance the power coefficient of Savonius wind rotors. The device with the guide box tunnel with the area ratio 0.43 has increased the performance 1.5 times more than the device without the guide box tunnel. The study about the impact of the guide plate on the performance of the Savonius water turbine was learned by Golecha et al, in 2011. However, utilization of guide plates (Irabu and Roy, 2007; Altan et al, 2008) or guide box tunnel is made the structural system more complex and also rejected the ability to accept wind from any direction of the Savonius wind rotor.

Furthermore, the recent research has been used both methods, model and optimization algorithms. A study on a Horizontal Axis Wind Turbine (HAWT) operating a mixing of CFD simulations and neutral networks to determine the performance of the wind turbine was employed by Tu et al, 2007. This study was integrated into a genetic algorithms for optimization. Despite, CFD simulation was not used for every performance determinations. This is due to it needs an essential computational resource. Rather, the optimization on HAWTs by using Blade Element Momentum Theory (BEMT) have been accomplished by Cencelli et al (2006) and Dossing et al (2012) which locates a much less require on the computational resource. Nevertheless, this theory cannot use to optimize the Vertical Axis Wind Turbine (VAWT) studies. The design technique need to have a good experience and has enough ability in order to specify appetency the performance, but for the optimization process allows for designing to be generated more often than the design technique by a designer. Furthermore, because of its adaptability and accuracy, CFD was selected as a suitable tool to predict the new blade shape design of the Savonius wind turbine resembling lotus in shape performance.

2. LITERATURE REVIEW

2.1 Conservation Equation

If mass or velocity is considered as ϕ, then for control volume, the overall conservation equation can be expressed as the equation below.

$$\frac{d}{dt}\int_{CM} \rho\phi dV = \frac{d}{dt}\int_{CV} \rho\phi dV + \int_{CV} \rho\phi(\vec{v}-\vec{v}_b).\vec{n}dS \quad \text{(Eq. 1)}$$

This equation shows that the fluctuation of variable ϕ depends on the time rate for control mass is equal to the changes of the variable within the control volume plus the variable through the surface of the control volume of the net flux. The Reynold's transport equation is known from the general form of the conservation of variable ϕ.

If ϕ=1, the conservation of mass become:

$$\frac{\partial}{\partial t}\int_V \rho dV + \int_S \rho\vec{v}.\vec{n}dS = 0 \quad \text{(Eq. 2)}$$

If $\phi = \vec{v}$, the conservation of momentum become:

$$\frac{\partial}{\partial t}\int_V \rho\vec{v}dV + \int_S \rho\vec{v}\vec{v}.\vec{n}ds = \int_S \vec{T}.\vec{n}dS + \int_V \rho\vec{b}dV \quad \text{(Eq. 3)}$$

Where $\vec{T}$ is the stress tensor that responsible for the forces acting on the control surface of the volume, and $\vec{b}$ is the body forces which acting on the whole volume. If Gauss's theorem is employed to transform the integral of the volume into the integral of the surface,

$$\int_V (\nabla.\vec{F})dV = \int_S \vec{F}.\vec{n}dS \quad \text{(Eq. 4)}$$

Which shows that the divergence vector $\nabla.\vec{F}$ is equal to the vector flux that across the vector on the surfaces of the volume. So the conservation of mass for the small control volume becomes

$$\nabla.\vec{v} = 0 \qquad \text{(Eq. 5)}$$

It shows that the volume dilatation is equal to zero. By using the same approach, the conservation of momentum becomes

$$\frac{\partial \vec{v}}{\partial t} + \nabla.(\vec{v}\vec{v}) = -\frac{1}{\rho}\nabla p + \nabla.(v\nabla\vec{v}) + \vec{b} \qquad \text{(Eq. 6)}$$

3. METHODOLOGY

The objective of this study is to have enough capability to realize directly of the requirement performance, modular, and automated design framework. Figure 3.1 shows about the calculation process that's used in this methodology.

The general idea in this methodology are all of the modules can be replaced. The user can be used other optimizer in this case. So, any modules have been shown in figure 3.1. In this figure the calculation process has been generated step by step in order to approach the objective function. Therefore, it depends on the user how to communicate for each module.

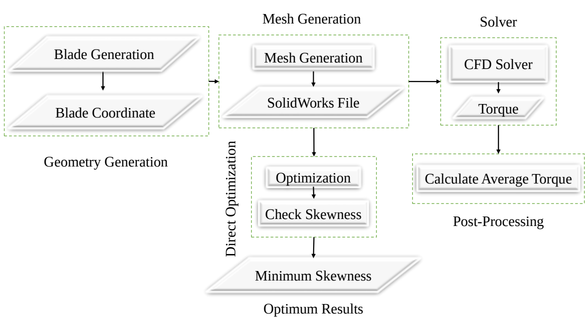


Fig. 3.1 Methodology

3.1 Computational Domain

In order to avoid the impact on the CFD's results, the suitable computational domain size is defined in this work. The dimension of the static zone called "Air Domain" is created by multiples of the rotor diameter. For the upwind, the dimension is extended 2 rotor diameter (2D), and 8D for the downwind direction. Furthermore, it also extends 3D for other directions. For the boundary conditions, the inlet velocity is defined, while the outlet pressure is assumed to be equal to the atmospheric pressure.

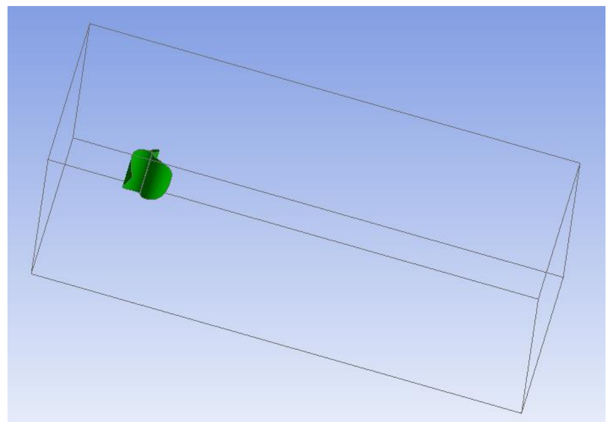
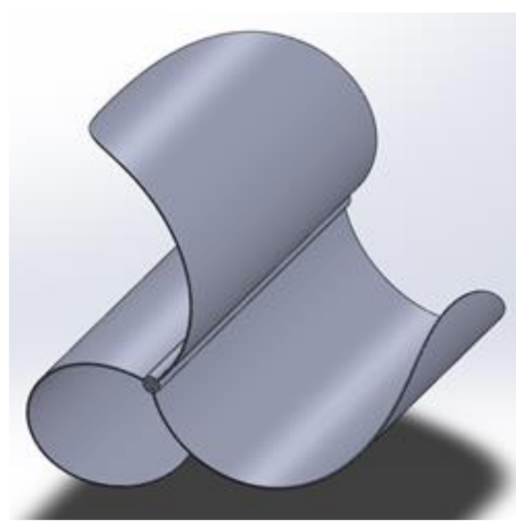


Fig. 3.2 Illustrate of Air-Domain

Due to it has less visual impact and noise, the new blade shape of Savonius wind turbine resembling lotus in shape was chosen in this study. It is the most suitable type for the building and street lighting systems (Ricci et al, 2016).



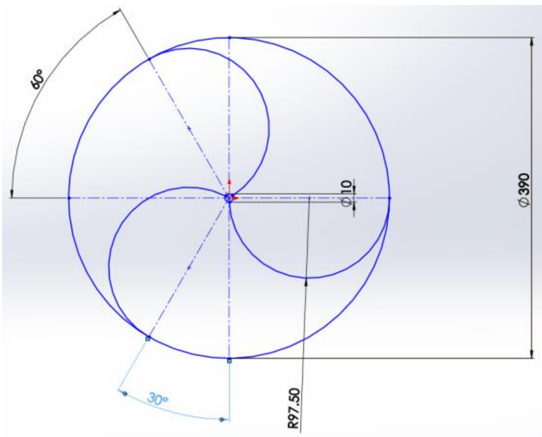


Fig. 3.3 Geometric parameter of Savonius wind turbine lotus in shape

Table 3.1 shows about the dimension, number of blades, and aspect ratio that used in this study. It contains three new blade design with 50° twist angle, and the aspect ratio is 1.1.

Table 3.1 Savonius wind turbine dimensions

Savonius Wind Turbine	
Number of blade	3
Maximum Radius (mm)	195
Aspect Ratio	1.1 (H/R)
Shaft Diameter (mm)	10
Height (mm)	216

3.2 Turbulence Modeling

It is so complex to calculate the fluid interaction with a VAWT. It leads to time dependent, turbulence, and wake flow during the blades rotate. Mostly, the turbulence is created by the fluid motion. Many authors consider the type of fluid flow either it is turbulence or laminar velocity depend on the Reynolds number. When the Reynolds number is high, the flow field becomes to three dimensional velocity with high fluctuations. A wide range of time and length is created by these fluctuations. In order to define the turbulent velocity, the spatial and temporary domain is distinguished and capture even the smallest turbulent structure. Hence, selection the turbulence modeling is so important and many numerical simulations is included, when the Reynolds average approach is known.

3.3 Direct Optimization

In fact, it was realized that the simple purpose of this study is to define the performance and automate the optimization of a mesh skewness. The optimization methodology proposed is to achieve the best skewness. Therefore, it needs to spend more time in order to succeed the analysis a solution and realize the physical problem. The direct optimization is a tool that utilizes real solves. It allows the users to use the existing design point, and it also reduces the time needed for the optimization process.

4. RESULTS AND DISCUSSION

The overall objective function of this study is to define the performance of the new blade shape of Savonius wind turbine resembling lotus in shape and to minimize the mesh skewness. Figure 4.1 and 4.2 show about the average torque coefficient and power coefficient. These results are plotted as a function with the tip speed ratio λ. The data were calculated under the velocity condition of 6.5 m/s. This velocity corresponds to the Reynolds number of 1.1×10^5. The average torque coefficient is maximum at $\lambda = 0.2$ and then it decreases when the tip speed ratio increases.

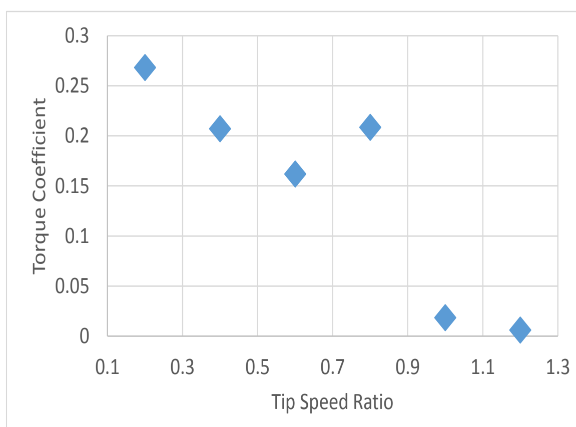


Fig. 4.1 Torque Coefficient

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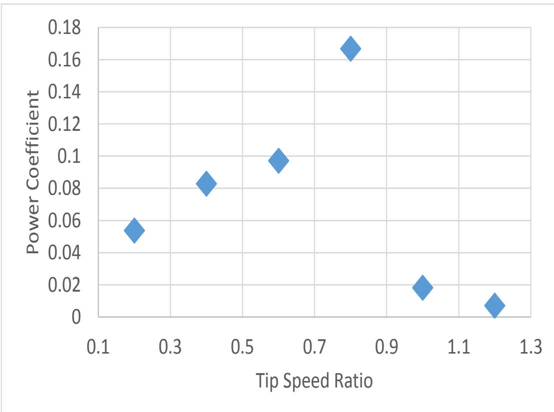

Fig. 4.2 Power Coefficient

Due to the curvature part is small, it leads the power coefficient between $\lambda = 0.2$, $\lambda = 0.4$, and $\lambda = 0.6$, have almost the same value. Furthermore, the maximum power coefficient is highest at $\lambda = 0.8$, and then it starts to decrease. According to Ricci et al (2016), the maximum power coefficient of Savonius wind turbine range from 0.10 to 0.25. So the power coefficient for the new blade shape is high enough.

In this study, screening method has been used in the optimization process with the 50 samples number and 2 candidates. Figure 4.3, the candidate result shows both the table and the chart view. Hence, from these figures, the best candidate result is 2.45E-01. It means that after generating the optimization, the skewness reduced from 2.61E-01 to 2.45E-01. Therefore, the skewness is 0.58% reduced.

1	Optimization Study		
2	Minimize P7 0<=P7<=26	Goal, minimize P7; Strict Constraint, P7 values between 0 and 26.	
3	Optimization Method		
4	Screening	The screening optimization method uses a simple approach based on sampling and sorting. It supports multiple objectives and constraints.	
5	Configuration	Generate 50 samples and find 2 candidates.	
6	Candidate Points		
7	P7-Mesh Average	0.24509	0.24652

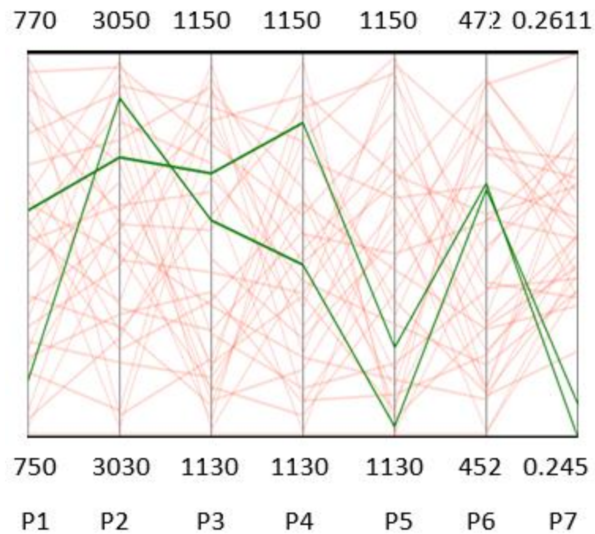

Fig. 4.3 Candidate Results

5. CONCLUSIONS

In the recent study, the new blade shape of Savonius wind turbine resembling lotus in shape has been built to make it looks like the lotus for its appearance. It is the most suitable device that can locate in the public area due to it was built as a flower or lotus for its appearance. Moreover, not because of its appearance only, but it also depends on the sound and self-starting performance. This wind turbine is a drag type wind turbine, so its speed is not faster than the air velocity, but due to this reason it makes this wind turbine good at self-starting although its efficiency is not height as other types of wind turbine. Furthermore, the three dimensional CFD simulation was used to define its performance, and the direct optimization was employed to minimize the mesh skewness. From the results, the torques have a little fluctuation from one point to another, so the new blade shape of Savonius wind turbine resembling lotus in shape has smooth running; especially, the maximum power coefficient is 0.16674, so the performance of this new blade design is high enough to generate the lamp for the building and street lighting system. Furthermore, after the optimization process was conducted, 0.58% is reduced for mesh skewness. Due to the Savonius wind turbine is a part of the green energy, it gains more and more attention during the last decades. Many authors try to

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improve its performance and some authors try to make it look more beautiful in order to integrate it into the building and street lighting system. Moreover, the optimization tool is also a good tool for the researcher and industrial design. It can generate many times to approach the best geometry or objective function without help from people, it spends less time than human practice and a little material, and it can avoid the human errors also. Therefore, this study is so important for the future research. It is also a part of the green energy and it has not affected to the environment. Especially, it can reduce the fuel consumption for the building and street lighting system. Furthermore, it can make the building or public area look more beautiful due its shape was built to look like a flower or lotus. Hence, for the future research, applying the different twist angle and new optimization tool will be conducted in order to improve its performance.

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