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Simulation Study of Wind Turbine System for Electric Powered Vehicle

Rino Andias[1], Sofian Mohd[2*], Fadhli Zulkafli[3], Djamal Hissein Didane[4]

[1]Fakulti Rekayasa Industri, Telkom University, Bandung, 40257, INDONESIA

[2]Aircraft System and Design Research (ASDR) Focus Group, Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[3]Aerodynamics and Propulsion Research (APR), Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[4]Department of Energy and Thermofluid Engineering, Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author

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Abstract: The present study investigated the airflow characteristics of wind turbine system to harness wind energy for electric powered pickup truck. The wind turbine consists of the rotating drag-type rotor installed in the duct casing for wind concentrator. The geometry of the wind turbine system was modelled using SolidWorks software. The additional features of guide vane, additional outlet channel and second rotor blade were implemented to improvise the performance of previous design. CFD simulation work was conducted using commercial software of ANSYS Fluent. Initial inlet velocity were set for three different values i.e. 16.7m/s (60 km/h), 25m/s (90km/h) and 33.3m/s (120km/h). The results obtained indicated that the new design of duct casing with guide vane is capable to increase the air speed. The circulated air trapped in the duct casing which caused the negative torque of the rotor blade to occur were significantly reduced and increased the angular velocity as the additional outlet channel was introduced in the system. In addition, the implementation of double rotor blades in the modified design tends to increase the power generated by a factor of 1.5 as compared to the single rotor blade system.

Keywords: wind turbine system, airflow, Savonius rotor, CFD simulation

1. Introduction

Wind energy is an environment-friendly source of energy that has huge potentials to satisfy the energy needs of the world [1], [2]. Wind turbines generate electricity by converting the kinetic energy in the air to mechanical energy. Then, a generator is used to convert mechanical energy to electrical energy. Most wind turbines operate with this simple principle. The concept of harnessing wind energy is by turning two or three blades around the rotor to generate mechanical power. As the air flow past the rotor, the pressure difference between the top surface and bottom surface of the blades forces the rotor to rotate. Then, the central shaft that is connected to the rotor will spin the generator to produce electricity [3]. A wind turbine can be installed on both land or offshore. A windy area with a proper airspeed is a suitable place to build a wind turbine. The introduction of the first generation of commercial ocean energy devices in 2008 saw the first

**Corresponding author: sofian@uthm.edu.my*
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units installed in Portugal and the UK [4]. Currently, there are three types of energy mechanism in offshore areas from how the energy can be generated and one of them is by using wind.

Nowadays, governments and stakeholders have put up their attention to renewable energy sources as the combustion of fossil fuels can be said as one of the main factors causing global warming [5], [6]. According to European Renewable Energy Council, sources of energy such as geothermal, biomass and wind are developing rapidly and capable of becoming more commercially competitive. It is projected that by the year 2040, half of the global energy will be supplied by renewable energy sources [7].

Fossil fuel combustion technology in transportation attributed to the high productions of pollutant which are detrimental to human health, cultivation and sensitive ecosystems hence rise the global warming issues [8], [9]. Electric-powered vehicle is observed as one of the potential technology that could reduce the dependency on that application of conventional fossil fueled vehicles. However, high production cost of electric vehicle restricted the application in commercial stage. Wind turbine powered vehicle is viewed as a potential technology in terms of operational simplicity and hence the cost effective. The installation of wind turbine system in electric vehicle is thus ensures the rechargeable continuation of power storage in the battery[10]-[13].

The inventions of wind turbine powered vehicle were previously developed with various system designs. Stoeckert [14] invented a roof top wind turbine using a drag-type blade installed in rectangular shape housing. Damron and Damron [15] developed a close system of a single rotating unconfined propeller, extension shaft, armature shaft and generator on the rooftop of vehicle. Laurent Michaud [16] proposed the operation of double propeller install at the front side of the vehicle. Drouin [17] invented a modular wind turbine device which attach under the hood of the car. The turbine blade is an elongated cylinder with protruding fins which moving as incoming air-flow circulated within the hood. To the best author knowledge, the detail study of flow and power output analysis of the wind turbine blade and system is scarce among all of the inventions. Therefore, the present study aims to investigate the optimum design of the Savonius wind turbine system in harnessing wind energy typically for pickup truck by evaluating the aerodynamic performance and power generation.

Savonius wind turbine is a simple vertical axis wind turbine (VAWT) device with a shape of half-cylindrical parts attached to the opposite sides of the vertical shaft (for two-bladed arrangement) and operates on the drag force[18], [19]. Therefore, it cannot rotate faster than the speed of wind. When the wind blows to the components and contact with the opposite facing surfaces which is a convex and concave surface, two types of forces which are drag and lift forces are exerted at those surfaces. The basic principle is based on the difference of the drag force apply between the convex and concave parts of the rotor blades when they rotate around the vertical shaft. Hence, the drag force is the most important driving force of the Savonius rotor [20].

2. Methodology

The present study used the wind turbine model in reference [21]. The reference model was then modified into a new design to improvise the aerodynamic and power output performance. All the reference and modified models were depicted as in Fig. 1.

2.1 Design Model

For reference model, the length, height, inlet and outlet width of the duct casing was 1000, 150, 1000 and 580 mm respectively whereas modified model attributed different length which was 1600 mm. The small outlet channels were added at the side region of duct casing right next to both rotors. The height and width of both channels were 150 and 108 mm respectively. The channel act to relieve the trapped air inside the duct casing and hence reduce the negative torque effects. The wind turbine was installed with three bladed drag type rotors. The height and diameter of the rotor were 130 and 528 mm respectively.

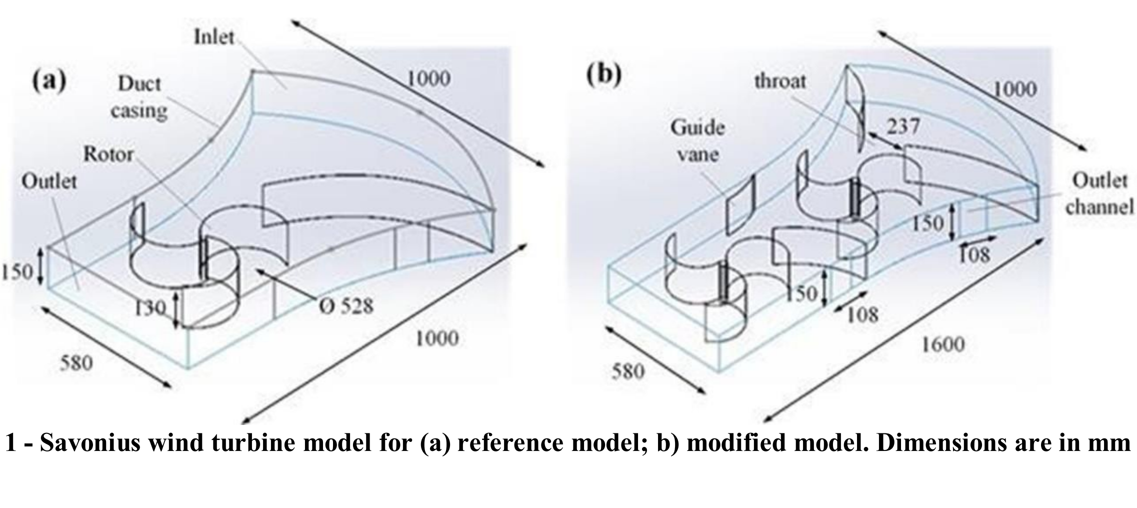

Fig. 1 - Savonius wind turbine model for (a) reference model; b) modified model. Dimensions are in mm

The flow analysis was conducted by computational fluid dynamics (CFD) simulation work using commercial software package of ANSYS Fluent. The analysis was then divided into 2 section; the first and second sections were the flow analysis of duct casing without and with the existence of wind turbine rotor respectively. The flow of analysis work for both section were presented as in Fig. 2. Power output was also estimated in the present study by using the following equation where P is power, C_p is power coefficient, is density, A is area, v is velocity, T is torque, is rotational speed, I is moment of inertia, is angular acceleration and t is time.

$$Wind\ turbine\ power\ \ (P) = \frac{1}{2} C_p \rho A v^3 \quad (1)$$

$$Wind\ turbine\ power\ (P) = T \times \omega \quad (2)$$

$$= I \times \alpha \quad (3)$$

$$\alpha = \Delta\omega / \Delta t \quad (4)$$

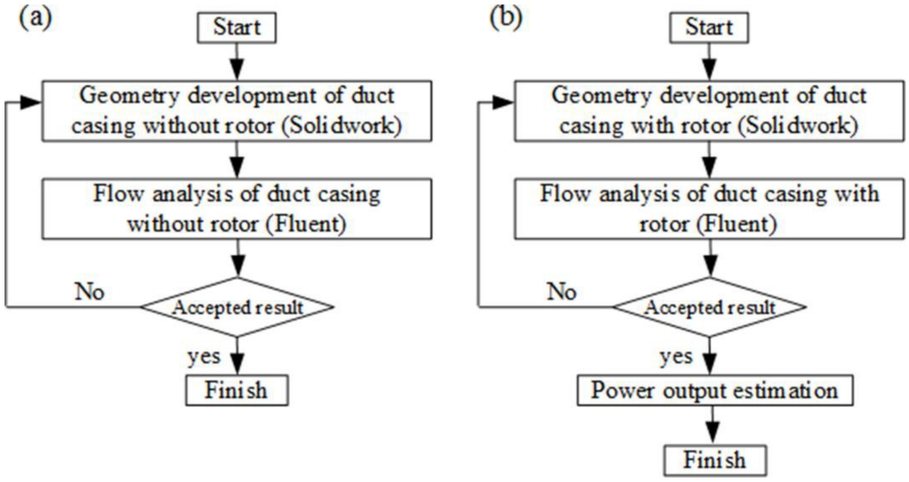

Fig. 2 - Analysis flowchart for (a) Duct casing without rotor; (b) Duct casing with rotor

2.2 Simulation Setup

The analysis of CFD simulation was performed using ANSYS Fluent software. Pressure-based and transient setup were used as solver configurations. The present analysis implemented Realizable k-epsilon method for turbulence model with enhanced wall treatment near the wall and second order upwind scheme to solve momentum and turbulence kinetic energy equation. Velocity inlet boundary condition with three different velocity cases based on the normal cruising speed of the pickup truck (60 km/h, 90 km/h and 120 km/h) were used as shown in Table 1. Atmospheric pressure outlet and no-slip wall boundary conations were adopted at the outlet position and at the wall surfaces of the rotors, respectively. Details of boundary condition setup are tabulated in Table 1.

Table 1 - Boundary Condition

Velocity Inlet [m/s]	16.7, 25 and 33.3
Turbulence Intensity [%]	5
Turbulence Viscosity ratio	10
Pressure Outlet [Pa]	0
Density [kg/m3]	1.175
Viscosity [kg/ms]	1.7894×10^{-5}

3. Results and Discussion

3.1 Verification and comparison between Reference Model and Modified Model

The velocity contour of duct casing without rotor for reference and modified model were compared and analyzed as depicted in Fig. 3. The reference and modified model were exhibited maximum velocity of 155m/s and 172 m/s respectively. Thus, it was clearly shows that modified model increase the maximum velocity by 11% as compared to reference model. Keep in mind that the modified model was specifically designed for installation of double rotor rather than reference model which can only fitted with a single rotor. Hence the flow contour was longer for modified model than reference model.

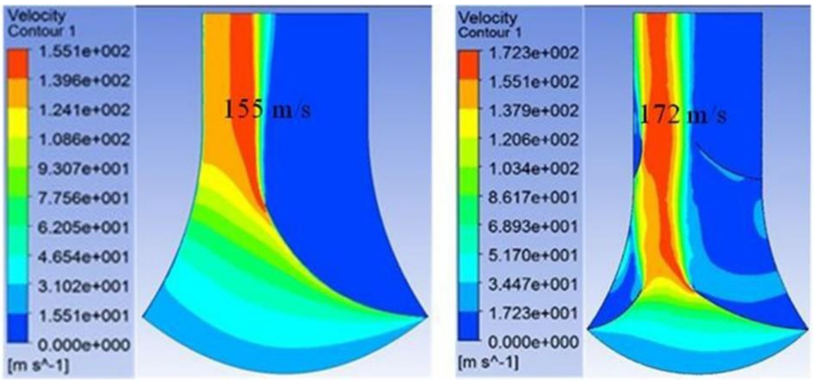

Fig. 3 - Velocity contour of duct casing without rotor for (a) reference model; (b) modified model

3.2 Comparative Flow Analysis between Modified Model with and without Additional Outlet Channel

Fig. 4 shows the velocity contour distribution of duct casing with the presence of rotor. The analysis also compared the difference of velocity contour between the duct casing with and without the existence of additional outlet channel. The initial value of inlet velocity was set at 25m/s which is in accordance with the typical cruising speed of pickup truck. The simulation results show that the velocity and angular speed after passing the first guide vane right before reaching the blade surface was 140 m/s and -833 rad/s respectively as shown in Figure 5a. Whereas the velocity and angular speed were 105 m/s and -405 rad/s after passing through the second guide vane. The negative sign indicates the clockwise direction of rotating rotor.

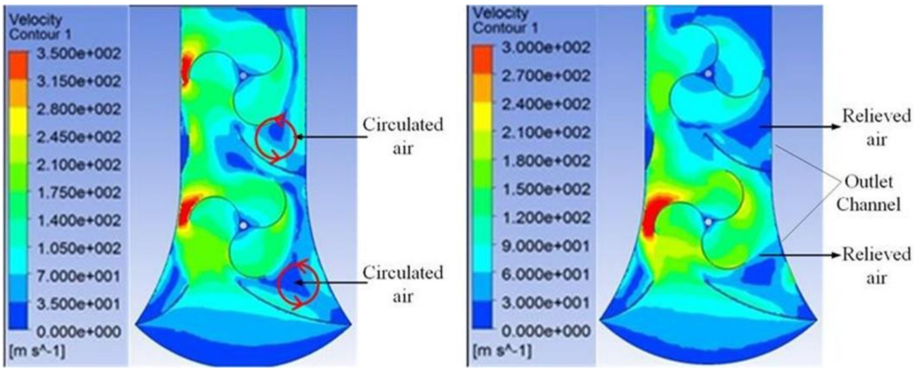

Fig. 4 - Velocity contour of modified model (duct casing with rotor) (a) without; (b) with additional outlet channel

Fig 4 - (a) also shows the existence of circular motion of air flow in the region surrounded within the returning blade of wind turbine, side wall and guide vane. The trapped air seems become an obstacle to the movement of returning blade hence increase the negative torque effects. Thus additional outlet channels were introduced to relieve the trapped and circulated air thus improves the rotational motion of rotor as illustrated in Fig. 4 - (b). The flow improvement by introducing those additional outlet channels could be observed through the value of angular velocity. The angular velocity with the presence of outlet channel increase from -833 to -940 and 450 to 460 rad/s for rotor 1 and rotor 2 respectively which equivalent to the increment of 15%.

3.3 Rotor Blade Performance for Modified Design

The next section was the analysis of power estimation as a function of different initial inlet velocity which in this case are 16.7 m/s, 25 m/s and 33.3 m/s. The results of maximum velocity and power from the simulation were plotted as in Fig. 5. The power output was estimated based on equation 1. The maximum velocity and power was generally increases with the increase of inlet velocity for both rotors. In addition, rotor 1 was typically exhibited higher maximum velocity and power value compared to rotor 2.

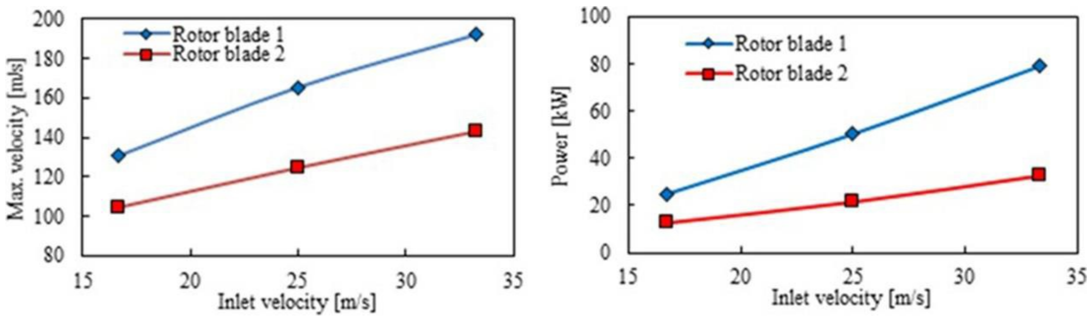

Fig. 5 - The performance of rotor blade 1 and 2 for (a) Maximum velocity; (b) power output as a function of inlet velocity

Fig. 6 shows the estimated torque and angular velocity based on the simulation result for both rotor blades 1 and 2 as a function of initial inlet velocity. The angular velocity and torque were typically increased with the increase of inlet velocity. Rotor blade 1 shows higher angular velocity compared to rotor blade 2 as the air velocity after passing the first guide vane was higher than the second guide vane. Surprisingly, the rotor blade 1 exhibited lower torque value than rotor blade 2. The rotation of rotor 1 seems to pushing and compacting air from the first guide vane. The compact air is then further concentrated by the second guide vane caused the force impact as well as torque exerted on the rotor 2 to increase.

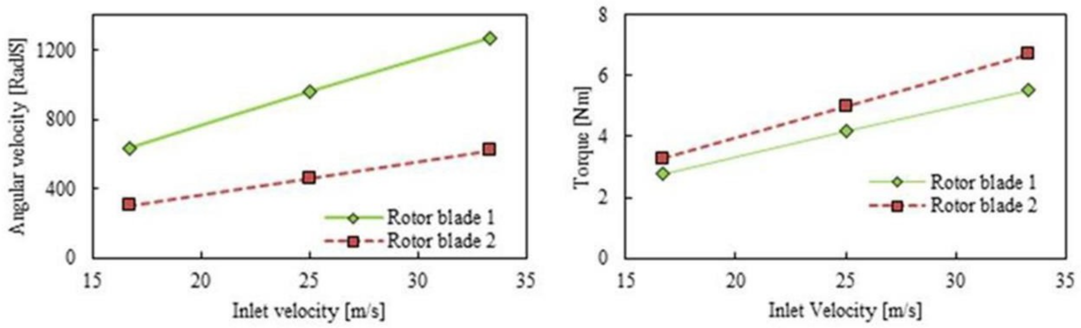

Fig. 6 - The performance of rotor blade 1 and 2 for (a) Angular velocity; (b) Torque as a function of inlet velocity

4. Conclusion

The flow analysis of wind turbine system for electric powered pick-up truck was conducted by the CFD simulation of ANSYS Fluent software. It is concluded that the modified design of duct casing without the presence of rotor improved the airflow by velocity increment of 11% compared to the reference model. Moreover, the presence of additional outlet channel in modified design eliminated the formation of circulated air within the duct casing which caused the negative torque effects on returning blade to increase. The improved air flow by outlet channel was indicated by the increment of angular velocity of 15% compared to those without the outlet channel. Furthermore, it was indicated that the maximum velocity in duct casing, power, torque and angular velocity of rotor are typically increased with the increase of the inlet velocity. Rotor 2 exhibited lower power, velocity and angular speed but higher torque value compared to Rotor 1. The higher air force exerted on Rotor 2 due to air compaction by rotor blade 1 and air concentrator by guide vane, cause the torque value to be higher.

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