Flow Simulation of Modified Duct System Wind Turbines Installed on Vehicle

N Rosly¹, S Mohd², M F Zulkaflî³, M F Abdul Ghafir⁴, S S Shamsudin⁵, W N A Wan Muhammad⁶

¹,²,⁵,⁶Aircraft System and Design Research (ASDR) Group, Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein Onn Malaysia
³,⁴Aerodynamics and Propulsion Research (APR) Group, Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein Onn Malaysia

Corresponding author: ¹nurhayati@uthm.edu.my

Abstract. This study investigates the characteristics of airflow with a flow guide installed and output power generated by wind turbine system being installed on a pickup truck. The wind turbine models were modelled by using SolidWorks 2015 software. In order to investigate the characteristic of air flow inside the wind turbine system, a computer simulation (by using ANSYS Fluent software) is used. There were few models being designed and simulated, one without the rotor installed and another two with rotor installed in the wind turbine system. Three velocities being used for the simulation which are 16.7 m/s (60 km/h), 25 m/s (90 km/h) and 33.33 m/s (120 km/h). The study proved that the flow guide did give an impact to the output power produced by the wind turbine system. The predicted result from this study is the velocity of the air inside the ducting system of the present model is better that reference model. Besides, the flow guide implemented in the ducting system gives a big impact on the characteristics of the air flow.

1. Introduction

There have been many improvements introduced in powered-electric vehicles by using electricity such as hybrid cars and battery-operated electric vehicles. The term hybrid commonly refers to hybrid electric vehicles (HEVs), which combine an internal combustion engine and electric motors to generate extra power [1]. For this study, the wind turbine system has been designed in a way that it can produce external power source that will be applied to the pickup truck. The system mounted on the vehicle is going to charge the batteries of the HEV when it’s moving [2].

The capability of wind turbine system depends on few constraints to generate electrical power. The first consideration that needs to be considered is on the appropriate design of wind turbine system that consists of the turbine rotor and ducting system. The rotor chosen to be installed in the turbine system is the Savonius type of turbine rotor. Savonius wind rotor is one of the vertical axis wind turbines that has simple structure, low operating speeds and an ability to capture wind from any directions. The rotor is made up of two semi-cylinders with S-type cross sectional blades in which wind power acts perpendicular on the blades and converts into rotating motion of the central shaft [3]. A studied ran by Alexander and Holownia [4] founds that the performance of the Savonius rotor depends on blades aspect ratio, shielding and end plates. They concluded the increment of aspect ratio lead to better improvement in rotor performance. Supported by other studies [5], they concluded that the rotor blade
with shielding and end plates gives better efficiency than that without shielding and end plate. Furthermore, a study covered by Nasef et al. [6] on the aerodynamic performance of Savonius rotor in static and dynamic conditions shows that a suitable model for simulating the flow pattern around the Savonius rotor for both stationary and rotating cases is SST k–ω turbulence model.

This work focused in numerical design and simulation. The design process of the turbine rotor and ducting system is done using a design software, SolidWorks, while the flow field of the air flow inside the turbine system is evaluated by using computer simulation software, ANSYS Fluent. In the simulation, the air is considered as a viscous fluid and is modelled with SST k-ω turbulence model. The purpose of this research is to propose an optimum design of wind turbine system for pickup vehicle.

2. Modeling of Wind Turbine Ducting System

Based on the previous inventions by Mohd et al. [7], this turbine model is chosen as a reference model in order to create a new turbine system model. Based on this turbine model, the appropriate size that is going to be used for the new turbine design is set as 1000 mm length, 1000 mm width and 150 mm height [7]. In the turbine system, there is one part of the system, namely flow guider, was installed. The purpose of the flow guider is to increase the velocity of air and eliminate the moment occurring in an opposite direction for the rotation on the blade of the rotor without making any changes in the basic structure of the conventional Savonius wind rotor. The location of the flow guider has been set for this study is shown in Figure 1.

The second thing to consider in this study is to find the appropriate design and configuration of the rotor. Savonius type is used with respect to the air flow at the roof of the pickup truck body and axis of the wind turbine rotor. The whole body size is set to be 130 mm height and 1000 mm width. Previously, Mohd et al. [7] mentioned that the optimum overlap ratio (e/d) value has been found as 0.18. This ratio value of Savonius rotor is implemented in this study.

The present design is consists of one Savonius rotor with triple blades configuration. The rotor will be located after the flow guider near the outlet section of the ducting system. A thickness of the rotor has been set as 2 mm with a diameter of $d = 528$ mm, a rotor height is set as 130 mm and the gap distance of the turbine blade from centre of rotation, $e$ is 10 mm. Figure 2 shows the dimension of the Savonius wind rotor located at the inlet of the wind turbine.

![Figure 1. Location of the flow guider in the turbine model.](image1)

![Figure 2. Savonius wind rotor chosen](image2)
3. Aerodynamic Performance of the Ducting System
The performance of ducting system between present model and reference model [1] is compared and evaluated in order to validate the present design. The evaluation is based on the air flow inside the turbine’s system. Figure 3 shows the characteristic of the air flow inside of the ducting system for both models. During the simulation, the air velocity flows through the inlet is set to be 25 m/s which assume that the pickup truck is moving at 90 km/h. Based on the result obtained from the simulation, each design shows different location for the fastest air flow which proven that the velocity of the air flow is affected by the ducting design.

Based on the result obtained for model shown in Figure 3(b), the highest velocity of air inside the ducting system is at 135.6 m/s. Compared to the previous invention model invented by Nik Samsul Bahari [1], the maximum air velocity flows inside the ducting system is at 82 m/s. Therefore, it can be concluded that the current model is much better compared to the previous invention. In addition, based on the simulation results, it shows that the velocity of airflows inside the present model before it hits the turbine blade is approximately between 99.6 m/s -105 m/s for present model and velocity for Nik Samsul model [1] is only approximately between 78.5 m/s – 85 m/s. From the result, clearly, we can see that the velocity of the present model at neck region is higher than the Nik Samsul model. From the figure shown also, the air velocity inside turbine duct with flow guide before it hits the turbine’s rotor was increased four times (25 m/s at the inlet and 99.6 m/s at neck region) with additional flow guide at the inlet of turbine duct. This would justify that the design of the ducting system with application of flow guide increases the velocity of airflows inside the model.

![Figure 3](image_url)

(a) Nik Samsul Model [1]  (b) Present model

Figure 3. Velocity characteristic of air flows inside a wind turbine model

4. Analysis of Ducting System With Installed Rotor
Dynamic simulation has been performed to investigate the rotation of the rotor driven by the air that flows into the system. This is important to determine the rotation speed of the rotor which will be used to calculate the power output generate by the system. Figure 4 shows the velocity contour of the ducting system with the installed rotor. The inlet of the air velocity was set at 25 m/s which is equivalent to 90 km/h. Based on the simulation result, the rotor is rotating in clockwise direction at an average angular speed of 405.8 rad/s. The speed of the rotation is calculated from the average linear velocity of the rotor’s tip, which is 102.15 m/s.
In addition, the circular section shows that the air does flow in between the gap of the rotor and the flow guide. As the consequences, the air flow will create a negative torque which will cause in the reverse movement direction of the rotor. The rotor will experience slow rotation movement because of the negative torque produced. Therefore, a new model has been produced to counter the problem. The new model was made based on the modification of the flow guider.

5. Analysis of Modified Flow Guide
The modification is made on the flow guide to the ducting system. The flow guide is extended to a new length, i.e. made the gap distance smaller. The reason is to reduce the amount of air flow that moves in between the gap of the flow guide and rotor, which will create negative torque. Figure 5 shows the velocity contour of the modified ducting system installed with a rotor. From the circular section shown in the figure, we can clearly see that less portion of air moves into the gap between the rotor blade and flow guide compared to the previous model. Therefore, the rotation of the rotor will be less affected because of less negative torque created.

Figure 4. Velocity contour of the air flow inside the ducting system with motor

Figure 5. Velocity contour of air characteristic in wind turbine
In order to investigate the effect of the flow guide plate and to identify the speed of the air flow inside the ducting system with turbine rotor, simulation is performed on the Savonius wind turbine rotor system. For this simulation, the inlet velocity has been set at 16.7 m/s, 25 m/s and 33.3 m/s. The result (Figure 6) shows that the velocity of air at the neck of duct before it hits the turbine rotor increase about four times for each speed set at the inlet. The figure also shows that air velocity inside the duct system before it hits the turbine blades decreased around 20-25% because the blade acted as a barrier that prevents air flow to enable it to rotate and generate power for wind turbine system.

(a) Inlet velocity = 16.7 m/s
(b) Inlet velocity = 25 m/s.
(c) Inlet velocity = 33.3 m/s

Figure 6. Velocity contours of wind turbine with modified flow guide

Based on the figures shown, the rotation speed of the blade can be estimated based on the maximum air flows that hit the turbine rotor. It is important to evaluate the rotation speed or angular velocity, $\Omega$, of the rotor in order to calculate the power generated by the wind turbine system. The calculation of the angular velocity is computed based on the average linear velocity of the tip rotor, $V_{tip}$, obtained from the simulation and the diameter of the rotor, $d$ as shown in equation (1). The calculated value of the angular velocity will be used to calculate power generate by the system.

$$\Omega = 2 \frac{V_{tip}}{d}$$

Table 1 shows the summarization of the angular velocity of the rotor calculated based on three different inlet velocity of the system. The relation between the inlet velocity and the calculated angular
velocity is depicted in the graph shown in figure 7. Clearly the angular velocity does not increase linearly and slowing down even the inlet velocity is increased. The reason is the flow rate of air that moves through the gap increased and will create significant negative rotation as the inlet velocity increased. Therefore, it can be deduced that the proposed wind turbine design will become less efficient during high speed vehicle movement since the high inlet velocity will produces more air resistance to the rotation of the rotor.

Table 1. Value of calculated angular velocity

| Inlet velocity (m/s) | Average tip velocity, $V_{tip}$ (m/s) | Angular Velocity, $\Omega$ (rad/s) |
|----------------------|--------------------------------------|----------------------------------|
| 16.7                 | 75.2                                 | 284.8                            |
| 25                   | 130                                  | 492.1                            |
| 33.3                 | 145.5                                | 550.7                            |

Figure 7. Relation between inlet velocity and angular speed of the rotor

6. Conclusions

The capability of the wind turbine as a machine that converts kinetic energy into electrical energy to produce electrical power could be used in the vehicle. The characteristics of the air flow inside the wind turbine system and output power generated by the system were evaluated.

The air velocity at the inlet of the system was set at 16.7 m/s, 25 m/s and 33.3 m/s which are equivalent to standard vehicle cruising speed of 60 km/h, 90 km/h and 120 km/h. Based on the simulation result, the air velocity was slightly increased at the ducting neck region. The air velocity was significantly increased such as four times of the inlet velocity with the implementation of the flow guide. Therefore, there are few things that can be summarized as the conclusion based on the result obtained:

(a) The air velocity in the ducting system for the present model is much better than reference model [1] as the average highest for present model: (99.6 – 105) m/s compared to reference model: (78.5 -85) m/s.

(b) The air velocity at neck region did increase four times of the inlet velocity: (25-99.6) m/s.

(c) The designation flow guide does give a big impact towards the rotation of the rotor since it can be designed to prevent the negative torque that can encounter the rotor rotation.
(d) The rotation speed of the rotor is higher for the modified model compared to the initial model with the rotor.

(e) The modification made on the flow guide did increase the velocity of the air flow inside the ducting system but will become less effective during high speed vehicle movement.

Acknowledgment
This project was supported by Exploratory Research Grant Scheme, ERGS under Grant Vot. No: E034 in order to conduct the research.

References
[1] Mohd S, Mohamad Zainu N S B, Rosly N and Abdullah A 2016 Aerodynamic characteristics evaluation of wind turbine dusting system performance for pick up truck ARPN J. of Engineering and Applied Sciences 11 pp 11165-69
[2] Mohd S, Rosly N, Zulkafli M F, Mohamad Zainu N S B, Abdullah A, Shamsudin S S and Wahab A A 2016 Proposed design of wind turbine systems on a pickup truck ARPN J. of Engineering and Applied Sciences 11 pp 11160-64
[3] Manwell J F, McGowan J G and Rogers A L 2010 Wind energy explained: theory, design and application second edition John Wiley & Sons
[4] Alexander A J and Holownia B P 1978 Wind tunnel tests on a savonius rotor J. of Industrial Aerodynamics 3 pp 343-51
[5] Mahmoud N H, El-Haroun A A, Wahba E and Nasef M H 2012 An experimental study on improvement of Savonius rotor performance Alexandria Engineering Journal 51 pp 19-25
[6] Nasef M H, El-Askary W A, Abd El-Hamid A A and Gad H E 2013 Evaluation of savonius rotor performance: static and dynamic studies J. of Wind Engineering and Industrial Aerosdynamics 123 pp 1-11
[7] Mohd S, Rosly N, Rexca A J, Shamsudin S S and Abdullah A 2014 An evaluation of drag coefficient of wind turbine system installed on moving car Applied Mechanics and Materials 660 pp 689-93