Performance of the prototype shaftless small scale horizontal wind turbine for electricity generating from industrial exhaust air system

Wachira Putticaem¹, Yuttanant Boonyongmaneerat², Pakpachong Vadhanasindhu³ and Sompong Putivisitisak⁴*

¹ Technopreneurship and Innovation Management Program, Graduate School, Chulalongkorn University, Bangkok 10330, Thailand
² Metallurgy and Materials Science Research Institute (MMRI), Chulalongkorn University, Bangkok 10330, Thailand
³ Faculty of Commerce and Accountancy, Chulalongkorn Business School, Chulalongkorn University, Bangkok 10330, Thailand
⁴ Advanced Computational Fluid Dynamics Research Unit, Department of Mechanical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand

*Email: sompong.pu@chula.ac.th

Abstract. Man-made or unnatural wind from the industrial exhaust air system is an alternative wind resource for countries with natural low-speed or intermittent wind such as Thailand. It has strong and consistent wind speed when compared to the natural wind, with velocity about 5 to 10 m/s at a distance of 5 cm from the exhaust air outlet. However, some negative impacts to the exhaust air system performance was observed when a conventional wind turbine was employed. The objective of this research is to feasibility study the practicality of a prototype shaftless small scale horizontal axis wind turbine (SSHWT) to generate electricity from the exhaust air of the industrial exhaust air system. Aerodynamic, blade and generator designs were addressed in this study to maximize energy output and minimize negative impacts to the performance of the original exhaust air system. The performance of SSHWT was tested with a selected industrial fan that is widely used in industrial sections. The results showed that the SSHWT could generate electricity with less negative effect to exhaust air system performance. However, it still needs further improvements caused by the voltage output is too low. By the concept design, this innovative wind turbine is compact, thus needs only small space for installation. This SSHWT has high market potential for low wind speed countries to take advantage of unnatural wind resources which are better in terms of efficiency and economy for sustainable energy development.

Keywords: Renewable Energy, Shaftless, Small Scale Horizontal Wind Turbine, Exhaust air system
1. Introduction

Energy is one of the key factors for economic and social development in every country. As energy consumption trends in the industry, transport, commercial, and residential had been increasing year by year, reliance on nonrenewable fossil-based leads to the vitality emergency. According to the growing risk of global warming and pollution, the search for clean and renewable alternative energy resources is one of the foremost pressing challenges to diminish the reliance on fossil assets and create sustainable development of human civilization. Wind energy is a part of the environmental friendly forms of natural energy to diminish the reliance on fossil assets. However, wind energy implementations are highly depended on geographical conditions, resources, cost, and government policies [1]. The Thai government’s objectives are to extend the renewable energy utilization to almost 25% of fossil fuel utilize and also plan to attain 1800 MW of power yield from natural wind energy by 2021 [2]. However, it is very challenging with Thailand's natural wind which is inconsistent and has a speed between 3 to 5 m/s [3] as shown in Figure 1.

Man-made or unnatural wind from the industrial exhaust air system as shown in Figure 2 are an alternative wind resource for countries with natural low-speed or intermittent wind such as Thailand. It has strong and steady wind flow velocity when benchmarked to the natural wind, with velocity about 5 to 10 m/s at a 5 cm distance in front of the exhaust air outlet. However, a major problem in the conventional horizontal wind turbine, when applied to generate electricity from the exhaust air of the exhaust air system, is negative impacts on the exhaust air system performance. Conventional horizontal wind turbines require 20 cm to 1.5 m distance away from the exhaust system [4]-[9] which is not suitable for installation in areas with limited space, especially in the urban areas.

The objective of this research is to feasibility study the practicality of a SSHWT to generate electricity from exhaust air of the industrial exhaust air system. Aerodynamic design, blade design, and generator design were addressed in this study to maximize energy output and minimize negative effects to the overall functioning of the conventional exhaust air system.

Figure 1. Map of wind power potential in calm wind conditions of Thailand [data and map from [3]].

Figure 2. Source of man-made wind; (a) Chiller in factory, (b) Condensing unit in residential, and (c) Exhaust fan in farm.
2. Literature Review

2.1. Development of wind turbine for electricity generating from the exhaust air system

Many researchers tried to demonstrate innovative ideas for energy recuperation from the exhaust air systems based on conventional horizontal wind turbines which consisted of blades, shaft, and generator [4]-[9]. Chong et al. presented an inventive idea to produce electricity from the exhaust air system in commercial buildings in urban areas by mounting the vertical axis wind turbines in front of the discharge of the cooling tower [10]. Negative impacts of the exhaust air system performance were observed when a vertical wind turbine was employed. Goh and Duan developed a prototype of 9-blade micro wind turbine with 110 mm rotor diameter to generate electricity from an air conditioner. It was found that the maximum power output was only 1.2 W at 2500 rpm rotation speed [11]. Thus, this design could not be spread for implementation. Even though the wind characteristics of the exhaust air system are strong, consistent and predictable but energy recovery from exhaust air systems for electricity generation in Thailand is still an emerging technology. The driven for implementation are device design, performance, and financial payback period. As a result, an innovative wind turbine is required to apply the existing theories and approaches to develop a suitable solution for electricity generations from the exhaust air system in the industrial section and urban areas.

2.2 Shaftless horizontal wind turbine for electricity generating

Most of inventive wind turbine design are based on conventional component such as blade, shaft, and generator and less observed for concept of shaftless horizontal wind turbine for electricity generating. The shaftless concept design was observed for propeller blade for marine to improve flow velocity [12]. For electricity generating, Elif et al presented the shaftless multi-blade wind turbine which fan blades were perpendicular mounted to the rotor frame [13]. And then, a rotor was assembled to the stator and supported by the bearings. However, the concern is still the negative impacts to the exhaust air system performance caused by blades which may block against exhaust air flow when rotate at high rotational speed.

3. Design Description of the shaftless small scale horizontal wind turbine (SSHWT)

3.1. Working principal of system and general arrangement

The objective of this SSHWT is to recover energy from the exhaust air of the exhaust air system for electricity generating with less negative effects on the exhaust system. The blades of wind turbine were mounted to the rotor frame with a tilt angle and rotation angle to make to open hole at the center of the wind turbine that the exhaust air can flow through the SSHWT to the environment. This design is proposed to minimize negative effects to exhaust fan performance and can be installed close to the exhaust fan as shown in Figure 3.

![Figure 3](image-url) Air streamline flow from the exhaust fan through the SSHWT.

![Figure 4](image-url) The design of the SSHWT.
3.2. Shaftless small scale horizontal axis wind turbine design and prototype
The SSHWT was designed, as shown in Figure 4. The major components are rotor and stator. The rotor, consists of blades, magnet, and wheels that mounted on the rotor frame. The SSHWT blades were mounted with a tilt angle and a rotation angle to make an open hole at the center of the wind turbine that the exhaust air can flow through the SSHWT to the environment with less negative effects to exhaust fan performance as shown in Figure 3. The rotor can be rotated in stator frame by the roller wheels when exhaust air flow through the wind blades. When the rotation began, the magnets would move across the copper coils that mounted on the stator frame to generate electricity. The specifications of the prototype are presented in Table 1.

Table 1. The details of the SSHWT prototype.

| Components        | Details                                                      |
|-------------------|--------------------------------------------------------------|
| Generator type    | Brushless                                                    |
| Rotor diameter    | 50 cm.                                                       |
| No. of blades     | 18 blades (flat blade, 6x15 cm, 1mm thick)                   |
| No. of coil       | 36 sets (Copper AWG20, 110 turns)                           |
| Rotor magnets     | NdFeB (N52) 40 sets, 1.25x5 cm, 3mm thick                    |
| Electric output   | Rectified DC                                                 |
| Gearing           | None                                                         |

3.3 Benefits of the shaftless small scale horizontal wind turbine designed
The SSHWT can generate electricity from the waste wind with a less negative effect on exhaust performance and flexible to install in the limited space area. As this design provided the open hole at the center, the exhaust air can flow through the SSHWT to the environment with less negative effects to exhaust fan performance. In addition, this innovative wind turbine is compact, thus needs only a small space for installation. Moreover, it can generate more electricity when compared to conventional horizontal axis wind turbines of the same rotor diameter.

4. Research Methodology
The possibility and concept design of the SSHWT were evaluated by research facility tests on an actual industrial exhaust fan. The outlet air flow profile determination, the effects of the SSHWT on the exhaust fan performance and the SSHWT performance are the major parameters to be explored in this test.

4.1 Exhaust flow velocity profile specifying of the industrial exhaust fan
The industrial exhaust fan used in this experiment is the commercialized propeller fan which is widely used in manufacturing factories and agriculture farms in Thailand. The velocities of the discharge air from exhaust fan at distances from the blade 5 cm along the axis were measured at varies radii of the fan blade using an anemometer.

4.2 Effect of installing SSHWT to exhaust system and SSHWT performance
This test is conducted in two configurations. First is the industrial exhaust fan without the SSHWT and the second is the industrial exhaust fan with the SSHWT. The test configurations are depicted in Figure 5.
Figure 5. (a) Test condition for industrial exhaust fan only, and (b) Test condition for industrial exhaust fan with SSHWT.

The experimental setup in the research facility test model is shown in Figure 6. The prototype was mounted in front of the discharge direction of the exhaust fan at 5 cm distance from the blade along the axis.

Figure 6. Research facility test model for the prototype of SSHWT installation

Several measurement had been recorded to distinguish the distinction between two test conditions. The current consumption of exhaust fan was measured by a clamp meter. The inlet air velocity of the exhaust fan is measured by an anemometer at 10 cm radius of the exhaust fan blade after the rotational speed of the SSHWT stable. All the parameters that are measured in the first condition (exhaust air system only) are replicated in the second condition. Additional parameters for second condition are rotational speed of the SSHWT and voltage output. The rotational speed of the SSHWT is measured by a laser tachometer. The SSHWT response time is measured by stopwatch to record the required time to realize its steady rotational speed. The voltage output of the SSHWT is measured by a digital multimeter.

5. Result and Discussion

5.1 Exhaust air flow velocity profile

The wind speed from the exhaust fan varies directly with the rotor radius (shown in Figure 7). Regression between outlet air velocity and rotor radius is not linear as shown in Figure 8. The maximum wind speed at the distance from the exhaust fan blade 5 cm along the axis occurs at 15 cm distance from the center. Therefore, position of the SSHWT blades must be related to the characteristics of the discharge air profile to the maximum performance of the SSHWT and exhaust fan.
5.2 Effect of SSHWT installation to exhaust system and the SSHWT performance

Table 2 shows the measurement results for both test conditions gotten from the research facility test. For the first condition (industrial exhaust fan only), the average of outlet air velocity at the discharge of the exhaust fan was 5.1 m/s. The current consumption of fan motor was 0.49 A. In addition, average inlet air velocity was 1.5 m/s. The measurement result of this test condition was taken as a reference all over the whole evaluation.

For the second condition (industrial exhaust fan with the SSHWT), it has been demonstrated that the SSHWT can be started manually and the average stable rotation speed was recorded at 1150 rpm. The Average outlet air velocity of the industrial exhaust fan show improvement (from 5.1 m/s to 6.9 m/s). This result showed that the installation of the SSHWT to the industrial exhaust fan is able to release more waste wind in to the environment and make the energy consumption of the exhaust fan comparable. The voltage output of the SSHWT is 1.2 V.

Table 2. Research facility test results of the SSHWT.

| Parameter                          | Industrial exhaust fan only | Industrial exhaust fan with the SSHWT |
|------------------------------------|-----------------------------|--------------------------------------|
| Current consumption of exhaust fan | 0.49 A                      | 0.49 A                               |
| Fan motor power consumption        | 110.4 W                     | 110.4 W                              |
| Average inlet air velocity         | 1.61 m/s                    | 1.76 m/s                             |
| Average outlet air velocity        | 5.1 m/s                     | 6.9 m/s                              |
| Rotational speed of the SSHWT *    | -                           | 1150 rpm                             |
| SSHWT response time                | -                           | 5 sec                                |
| SSHWT voltage output              | -                           | 1.2 V                                |

*The rotational speed of the SSHWT is measured when the RPM is stable.

6. Conclusion

The rotor diameter 50 cm SSHWT has been designed and fabricated to generate electricity from the exhaust air of industrial exhaust fan with blade diameter of 50 cm. The experiment was conducted on a feasibility study of the design. The result shows that the wind speed from the exhaust fan varies directly with the rotor radius in a non-linear fashion. The maximum wind speed is at a distance of 15 cm from the center at the distance from the blade 5 cm along the axis. Thus, the position of the SSHWT blades must be related to the characteristics of the discharge air from the fan for maximum efficiency. The SSHWT installing in front of the discharge outlet at distance 5 cm has no negative impact on the industrial exhaust fan. The voltage output is 1.2 V at the rotational speed of 1150 rpm. This system has
high market potential for low wind speed countries to take advantage of unnatural wind resources that are better in terms of efficiency and economy for sustainable energy development.

7. Future improvements

More comprehensive works are being done to realize superior arrangement and improve the performance especially the voltage output of the SSHWT such as the studies of the parameters optimization. Moreover, the effects of mixing the flow between the natural wind and exhaust air in the open area that maybe affect system performance will be conducted in further studies.

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