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# Improving Performance of Small Wind Turbine by Diffuser Augmented

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**Abstract**

The idea of using clean energy from unnatural wind resources is presented in this paper. Exhaust fan wind energy can be utilized to generate electrical energy through a small wind turbine. The potential is substantial as exhaust fans are widely used in the industry. The diffuse wind characteristics and medium to low speed of the exhaust fan require optimization to achieve maximum wind energy conversion. One optimization method involves adding a diffuser to enhance the wind turbine's performance by concentrating the wind around the rotor. The performance of the wind turbine and its influence on exhaust fan power consumption are investigated. The diffuser design follows the method developed by Yuji Ohya and Takashi Karasudani, involving a modification to the inlet angle. Simulation results demonstrate that the optimal inlet angle is 15 degrees. The optimal location on the wind turbine is 20 cm from the exhaust fan which produces the highest energy harvest. The addition of diffuser can increase turbine power bay 63.06%.

***Keywords*:** wind energy; exhaust fan; wind turbine; diffuser.

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## 1. Introduction

The dominance of fossil energy usage in Indonesia is evident, and its current decrease underscores the critical need to develop renewable energy sources. One technology that supports this transition is wind turbines [1,2]. To enhance energy efficiency in the industrial sector and commercial buildings, one approach is to utilize waste energy from exhaust fans. Utilization of wind energy from unnatural wind energy sources to produce electrical energy is one of the innovations in the field of new renewable energy. This energy is converted into electrical energy through a wind turbine. The optimal implementation of utilizing exhaust air from exhaust fans for power generation involves placing the wind turbine to face the exhaust fan air, ensuring a stable wind speed and a fixed wind direction [1, 13]. The chosen wind turbine is of the horizontal type, as it boasts higher efficiency compared to vertical turbines [2]. As part of the effort to further increase the turbine's efficiency, a wind diffuser sheath has been added. Incorporating a diffuser around the rotor of a horizontal wind turbine can amplify the wind flow speed at the rotor's tip, resulting in increased rotor rotation and enhanced power production. This use of a diffuser offers the advantage that the theoretical maximum power is not confined by the Betz Limit theory [3,14]. Utilizing diffusers emerges as a solution to enhance the performance of micro-scale horizontal wind turbines operating under low to medium wind speeds [4].

## 2. Literature Review

### *2.1. Wind Energy*

Wind energy results from the movement of air masses in the atmosphere, triggered by various factors. One primary cause is the uneven distribution of solar radiation across the Earth's surface. Solar radiation is absorbed by the Earth's surface and subsequently released back into the atmosphere. This occurs due to the heterogeneous nature of the Earth's surface—comprising land, water, deserts, forests, and more—leading to varying levels of solar energy absorption, contingent upon geographical locations. This uneven absorption of solar energy creates disparities in temperature, density, and atmospheric pressure. Consequently, it sets in motion the movement of air masses from one point to another. Wind energy, in essence, flows from areas of high pressure to regions of low pressure [5].

### *2.2. Horizontal Axis Wind Turbine (HAWT)*

Horizontal wind turbines operate on a propeller-like concept, specifically the Horizontal Axis Wind Turbine (HAWT), where the rotor rotates about a horizontal axis nearly parallel to the wind flow. This turbine type boasts several advantages. It exhibits a relatively high power coefficient value, offering efficiency in energy conversion. Additionally, the rotor speed and output power can be finely controlled by adjusting the pitch of the rotor blades. The aerodynamic design of the blades can be optimized, allowing for maximum efficiency, especially when exploiting aerodynamic lift to its full potential [5].

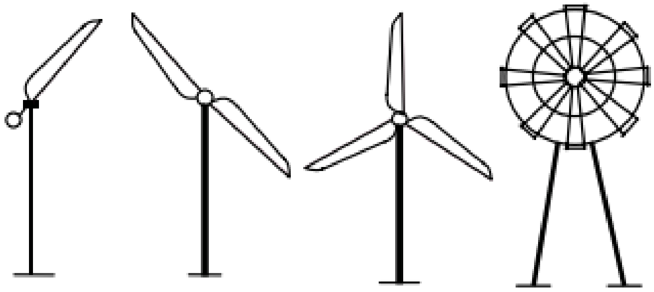

**Figure 1:** Horizontal Wind Turbine [6]

### *2.3. Exhaust Fan*

An exhaust fan is a device designed to expel hot air into the atmosphere. Typically found in large offices, buildings, and industrial settings, multiple exhaust fans are commonly installed. These fans employ blades driven by a motor to propel air outward through their blades [7]

**Figure 2:** Outlet Exhaust Fan in Industry [7]

The exhaust fan is strategically positioned between the indoor and outdoor environments to facilitate indoor air circulation. It operates by either drawing indoor air in or expelling it outward through the exhaust fan, allowing cool air from outside to replace the indoor air [8]

### *2.4. Wind Energy Conversion*

Wind turbines convert kinetic energy from the wind, a process dependent on wind power. Wind power is defined as the quantity of wind energy passing through a given area per unit of time. Wind energy, in turn, is characterized as the kinetic energy of moving air, where this energy is a function of both mass and fluid speed [9]. The kinetic energy is mathematically expressed using the following equation [9]

$$KE = \frac{1}{2} . m . v^2 \quad (1)$$

Wind power can be expressed with the following equation [13].

$$P = \frac{1}{2} . m \ . v^2 \qquad (2)$$

Where m is the mass flow rate which has the following equation [9].

$$m = \rho . A . v \qquad (3)$$

So, wind power can be expressed as the power through a cross-section, which can be formulated using the following equation [9].

$$P_w = \frac{1}{2} . \rho . A . v^3 \qquad (4)$$

### *2.5. Diffuser*

A diffuser is a wind sheath designed to enhance the efficiency of horizontal-type wind turbines. The primary objective of the diffuser is to capture more wind energy, consequently increasing the wind speed through the rotor and boosting the output power of the wind turbine. By incorporating a diffuser, it becomes possible to surpass the Betz limit value, specifically achieving a power coefficient exceeding Cp = 0.66 [5].

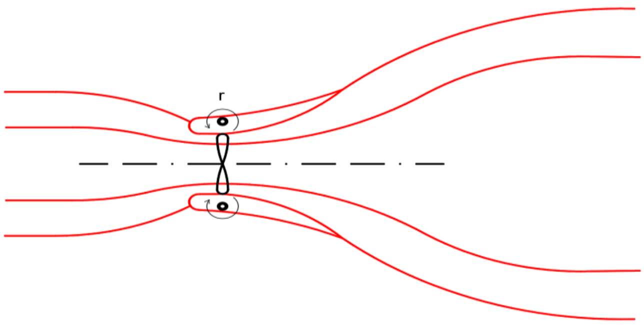


**Figure 3:** Ideal Flow Passing Through a Wind Turbine with a Diffuser [10]

A diffuser, or a hollow object exposed to free-flowing fluid, undergoes one of three effects: air flow suction, flow rejection, or no repulsion. In a diffuser, wind enters the shroud or draws in air from the inlet. The suction of air flow occurs when the air pressure within the diffuser is lower than the free air pressure (freestream), causing the air flow to move toward the lower pressure area, creating the impression of being drawn through the interior of the diffuser [11, 12, 13].

## 3. Method

### *3.1. Diffuser design*

The diffuser geometry design pertains to the Compact Brimmed Diffuser type developed by Yuji Ohya and Takashi Karasudani in 2010. This design was subsequently adapted to meet the specifications of the wind turbine used in our research. The diffuser design process was executed using the Autodesk Inventor application, with specific modifications made to the inlet angle of the diffuser. The detailed specifications of the designed diffuser are provided in Table 1 below.

**Tabel 1:** Diffuser specification

| Diffuser | Specifications |
|---|---|
| Throat Diameter (D) | 510 mm |
| Brim Height (h) | 51 mm (0,1 D) |
| Diffuser Length (Lt) | 150 mm (0,294 D) |
| Inlet Length (Lin) | 40 mm (0,266 $L_t$) |
| Outlet Length (Lout) | 110 mm (0,733 $L_t$) |
| Inlet Angle ($Ø_{in}$) | 5˚,15˚,30˚,45˚ |
| Diffuser Angle ($Ø_{out}$) | 10º |
| *Tip Clearance* (s) | 10 mm |

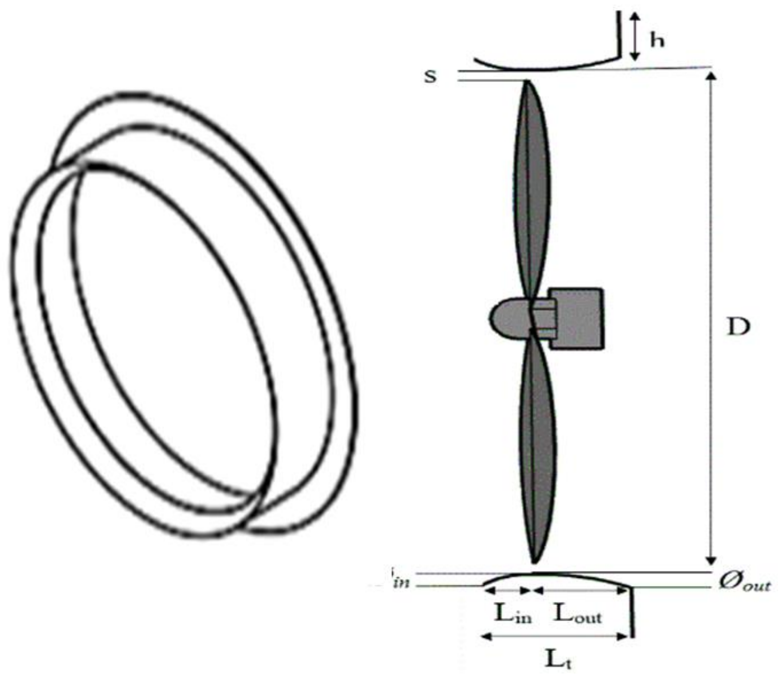


**Figure 4:** Diffuser Design Model

### *3.2. Diffuser Design Simulation*

The simulation of the diffuser model was conducted using the SolidWorks application, utilizing the

Computational Fluid Dynamics (CFD) feature to analyze the characteristics of wind speed within the diffuser. The outcomes of the CFD simulation are depicted in the figure below.

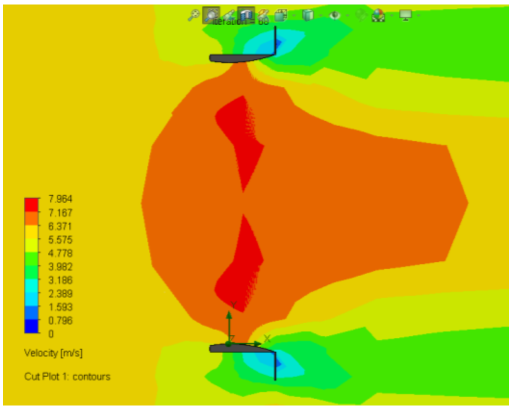


**Figure 5:** Simulation Resuts of Inlet Angle 5˚

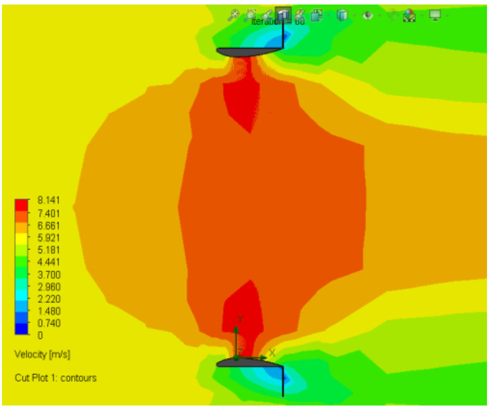


**Figure 6:** Simulation Result of Inlet Angle 15˚

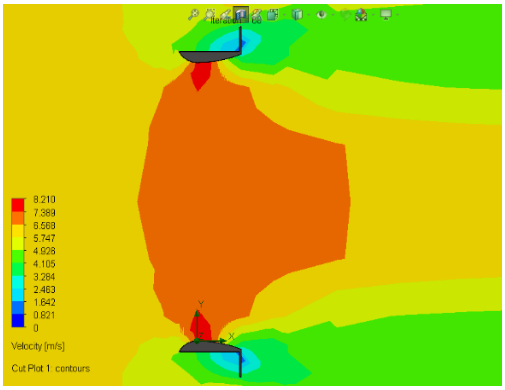


**Figure 7:** Simulation Results of Inlet Angle 30˚

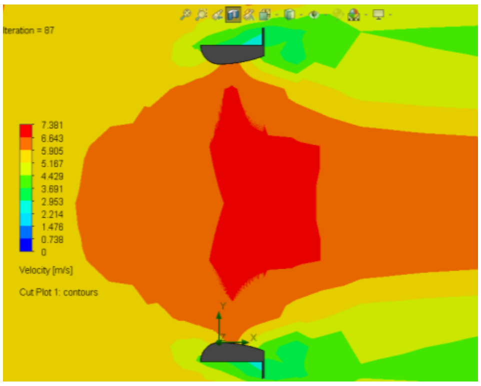


**Figure 8:** Simulation Results of Inlet Angle 45˚

Analysis of the simulation results reveals that an inlet angle of 15˚ produces an optimal wind speed, averaging 7.401 m/s, effectively covering the turbine blades as shown in figure 6. Consequently, the selected diffuser for the upcoming test will feature an inlet angle of 15˚.

### *3.3. Experimental Set-up*

The proposed model for a prototype design, utilizing exhaust fan air with a horizontal turbine and a diffuser, is illustrated in the figure below.

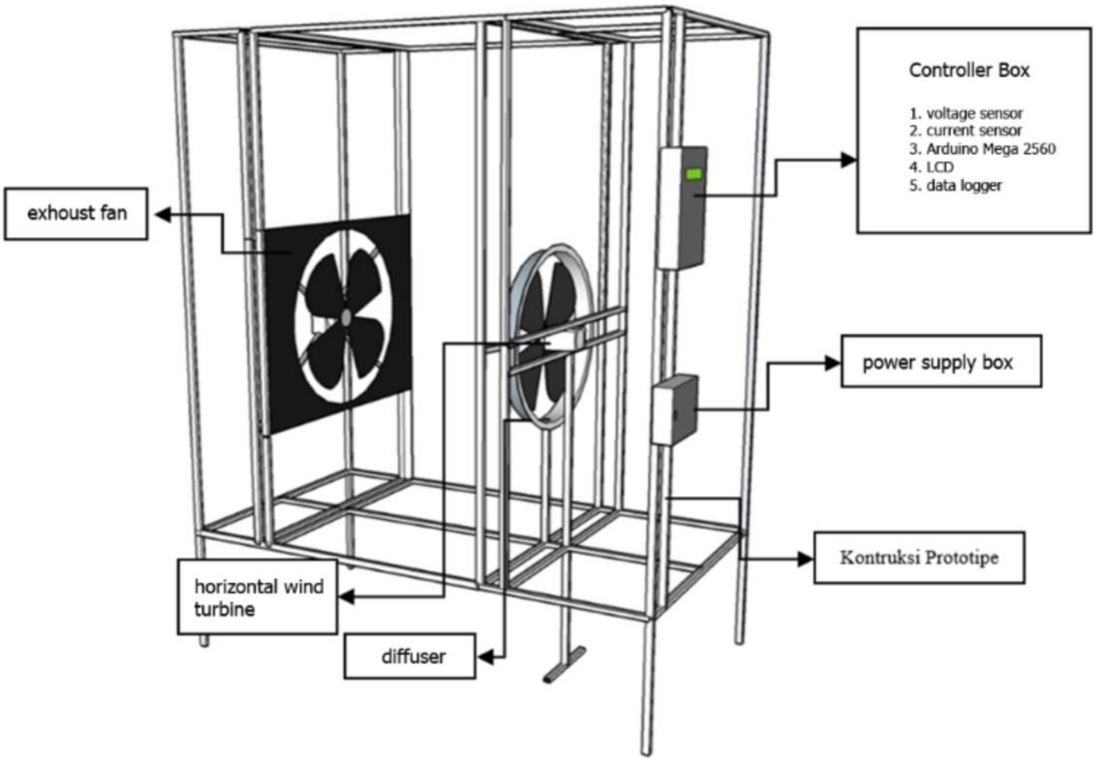


**Figure 9:** Measurement configurations

The exhaust fan serves as a source of wind energy, causing the horizontal turbine, equipped with a diffuser, to rotate as a result of the moving exhaust air. This rotation drives the rotor on the generator, generating electrical energy. Sensors for current, voltage, and turbine rotation speed are employed, with the data logger storing the measurement results. The turbine's placement is carefully arranged to ensure it does not impact the performance of the exhaust fan.

**Table 2:** Wind Turbine Specification

| Wind Turbine | Specifications |
|---|---|
| Number of Blades | 4 |
| Swept area | 49 cm |
| Blade Material | Metal |
| Generator Type | PMSG |
| RPM Generator | 5000 RPM |
| Generator Voltage | 2,8 – 24 VDC |
| Maximum Power | 36 W |

### *3.4. Results*

#### *A. Power harvest without diffuser*

The measurement results show that the power of the exhaust fan increases after adding wind turbine. The wind speed decreases further away, resulting in a lower output power of the generator. The optimal generator power occurs when the wind turbine is 20 cm away from the exhaust fan, resulting in a power harvest of 1.11 Watts.

**Table 3**: Measurement parameter without diffuser

| Distance (cm) | Nominal exhaust fan power (W) | Wind speed (m/s) | Power exhaust fan with turbine (W) | Increase exhaust fan power (W) | Turbine speed (RPM) | Power generator (W) | Power harvest (W) |
|---|---|---|---|---|---|---|---|
| 10 | 156.41 | 6.8 | 158.60 | 2.19 | 1579.20 | 2.42 | 0.23 |
| 20 | | 6.19 | 156.80 | 0.39 | 1232.64 | 1.50 | 1.11 |
| 30 | | 5.78 | 156.57 | 0.16 | 1067.03 | 1.06 | 0.90 |
| 40 | | 5.32 | 156.44 | 0.03 | 872.17 | 0.76 | 0.73 |
| 50 | | 4.97 | 156.43 | 0.02 | 788.53 | 0.61 | 0.59 |

#### *B. Power harvest with diffuser*

Measurement result after the wind turbine added diffuser are as in table 4.

**Table 4:** Measurement parameter with diffuser

| Distance (cm) | Nominal exhaust fan power (W) | Power exhaust fan with turbine and diffuser (W) | Increase exhaust fan power (W) | Turbine speed (RPM) | Power generator (W) | Power harvest (W) |
|---|---|---|---|---|---|---|
| 10 | 156.41 | 158.57 | 2.16 | 1816.12 | 3.03 | 0.87 |
| 20 | | 156.74 | 0.33 | 1432.73 | 2.14 | 1.81 |
| 30 | | 156.50 | 0.09 | 1229.30 | 1.56 | 1.47 |
| 40 | | 156.45 | 0.03 | 1055.54 | 1.07 | 1.04 |
| 50 | | 156.43 | 0.01 | 973.64 | 0.80 | 0.79 |

The measurement results show that power can be harvested both without a diffuser and using a diffuser, as depicted in the figure 10.

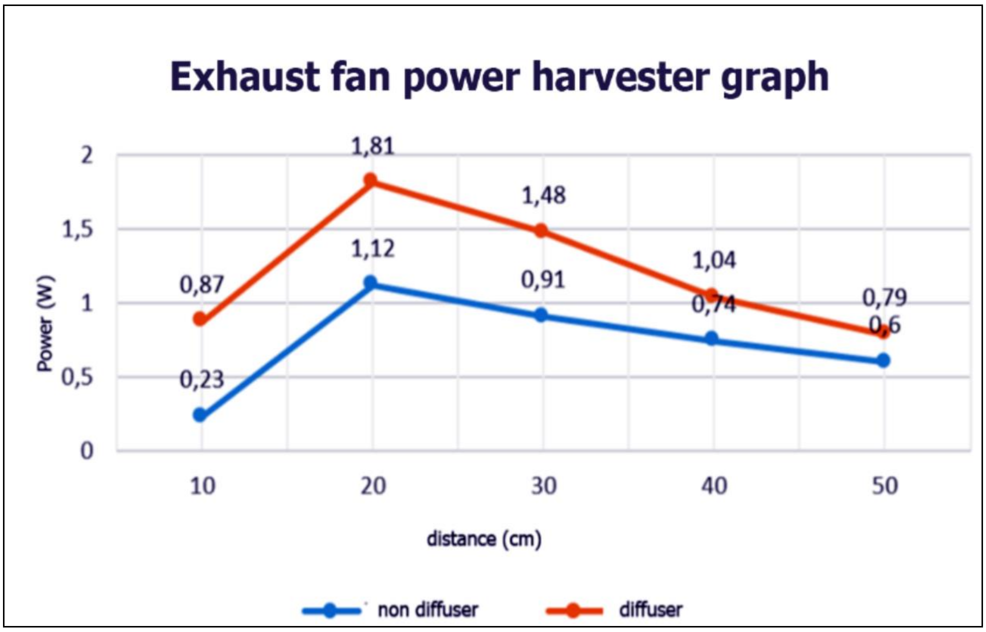


**Figure 10:** Power Harvesting Graphs

At a distance of 10 cm from the exhaust fan's turbine, the performance of the exhaust fan is diminished due to the obstruction of exiting wind. The most optimal power harvesting occurs at a distance of 20 cm, where a wind turbine equipped with a diffuser can yield 1.81 W of power, compared to 1.12 W without a diffuser. Therefore, the power increase when utilizing a diffuser is 61.6%."

## 4. Conclusion

The research conducted on an exhaust fan energy harvesting system with a horizontal wind turbine utilizing a diffuser has yielded the following conclusions:

1. The optimal diffuser inlet angle is 15 degrees.
2. The ideal turbine distance from the exhaust fan is 20 cm.
3. The utilization of a diffuser on a horizontal wind turbine can increase turbine power by up to 61.6%.

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