Tunnel Type Wind Mile Design

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Abstract. This study designs a tunnel type wind mill to increase the capability of wind energy capture. The main design works including the wind collection duct which can rotate along with the wind direction. This makes the wind enter the duct in best condition. After the wind enter the duct, both the direction of the duct is changed to vertical direction which makes the wind direction changes to downward. In the meantime, the diameter of the duct is also changed. The change of the diameter of the duct increases the speed of wind flow. A wind turbine with a nose is used to collect the wind energy. The nose makes the speed of the air flow increase more. In addition to the increasing the speed, the other advantage is to make the air flow flows to the outer part of the turbine blades. It is well known that the outer part of the turbine blade can get more energy than the inner part of the blade. This design can more wind energy than regular wind turbine.

Introduction

It is know by every one that the regeneraton energy is a very important energy source to reduce the CO₂ generation. The CO₂ makes the global warming, the reduction of the CO₂ generation is a very important isue[1,2]. Therfore, in past few decate, wind turbine become more and more important to a lot of countries. A lots of researchs of wind mill have been studied and some standard procedure had been developed [3].

Due to the limitations of traditional windmill configuration, the wind speed which is good to drive the windmills is limited. Therefore, researches on the ability to receive wind energy were constantly being carried out to enhance efficiency and power generation. In order to capture more wind energy, there are currently two common methods. One is to set up a tall windmill to receive more wind at high altitude or is to place the windmill in a place with high wind power (such as desert, at sea). Under this way, the wind turbine blades are driven by a larger wind speed to receive more wind energy. The other is to increase the efficiency of wind energy extraction; the focus of this method is to improve the shape of wind turbine blade to make it more capable of extracting wind energy. However, near the rotating shaft, the wind energy is difficult to fully utilize the wind. This always makes the starting wind speed is high of the wind mill. The other thing comes from the strength of the wind mill, the highest wind speed is limited. In order to solve the above problems, this study is dedicated to the design of the small windmill systems that utilize high wind energy utilization. Different from the current windmills, a shape variation duct which has a wind turbine inside it is used to grasp the wind energy. The variation of the duct diameter can increase the wind speed enter the duct, which increasing the efficiency of wind power use. In addition, because the turbine is hidden in the tube, it can reduce the noise of the windmill by noise isolation thus avoiding environmental and ecological damage and noise problems.

Design of the Wind Mill

Wind Collection Duct Design

As shown in upper part of Figure 1, the universal wind collecting device collects wind energy with a tail-winding air duct. The tail empennage function is to generate force so that the air duct can be steered by the wind without any external energy. In order to reduce the rotational resistance, a bearing is designed at the lower end, so that the universal wind collecting device can be turned to face the
wind source at any time without a strong wind. The universal wind collecting device can make the utilization of wind energy more efficient as the direction of airflow changes. In addition, a pressure relief valve is equipped at the proper position of the air duct. When the wind speed does not exceed the wind speed that the turbine can withstand, the valve is closed; but when the wind speed exceeds the wind speed that the turbine can withstand, the valve slowly opens with the wind speed. The part of the wind is vented; the amount of air entering the turbine is lower than the turbine cannot resist, therefore, even at very high wind speed the turbine can generate electricity. In this way, the range of wind speed of power generation is wider than that of a general windmill.

![Figure 1. Configuration of the wind mill.](image)

**Wind Energy Concentration and Wind Energy Conversion Device Design**

As shown in the lower part of Figure 1, the airflow collected by the universal air collection system then enters the wind energy concentration system. The shape of the pipe and the shape of the turbine head with a central conical guide head can be used to increase the speed of airflow into the universal air receiving system. The central conical guide head of turbine can force the airflow flow to the outer part of the turbine. In this design, the turbine blade exists only in the outer ring. It is found that the torque applied at the blade is large only at position which is away from the rotation shaft. The turbine head redirect the air flow flows to the rotation center away from the center to increase the efficiency of air energy collection. After the air passing through the turbine, the pipe diameter increases, and the wind speed is reduced. The advantage of the turbine in the pipeline is that it can be used to isolate noise (to solve the problem of windmill environmental protection). In addition, the concentration of wind energy can also reduce the minimum wind speed of power generation, and increase the ability to capture energy.

**Analysis of the Air Flow and Efficiency Analysis**

To design the duct of the wind collection device, the shape of the duct and the shape of the central conical guide head of turbine are designed by try and error of the results of different shapes of the duct of finite element method. Figure 2 shows the final results of the FEM analysis. It can be seen that the wind collecting device directs the wind from the horizontal to the turbine and the wind speed increases a lot.
In order to understand the situation that the system enters the turbine after the pressure relief valve open under high wind speed conditions, the following is the speed flow field simulated in ANSYS FLUENT, and observe the exhaust situation of the pressure relief valve. From Figure 3 and 4, it can be found that the pressure relief valve is open about 10°, when the inlet wind speed is 4m/s, the wind speed is reduced from 7.8 m/s to about 6.5m/s in front of the turbine blade. It is also found that when the inlet wind speed is 17m/s at the moment the pressure relief valve is opened to about 40°, the average wind speed is about 14.5 m/s in front of the turbine blade. It can be seen that the pressure relief valve effectively discharges the exceed wind, so that the turbine blades can continue to operate at high wind speed.

The other important work to do is to design the blade of the turbine. In this study, the ClarkY’s airfoil type blade is used for design and analysis. Figure 5 is the blade shape of our final design.
Follow the procedure of ref[3], the torque and output power of the windmill at different wind speeds and some certain speeds are shown in Table 1. In Table 1, the wind speed is 4m/s, the fixed radius R is 0.64 meters, the tip speed ratio of the tip is 8.913, and the radius of the guide head is 0.4R. According to the energy conservation, the wind is not considered for wear and the wind passes through the universal direction. The wind speed before the wind turbine and the wind energy concentrating device to the turbine is 7.14 m/s. It is noted that in this study, the 0.4 R is obtained by finding the place where the torque is low when computing the torque of the traditional windmill.

Table 1. Torque calculation of different position of the blade.

<table>
<thead>
<tr>
<th>Wind speed V(m/s)</th>
<th>Rotating speed n(rpm)</th>
<th>$C_L$</th>
<th>$C_D$</th>
<th>$V_B$ (N/m)</th>
<th>Q (N/m)</th>
<th>$\Delta TQ$ (N·m/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1R</td>
<td>7.14</td>
<td>950</td>
<td>0.7256</td>
<td>0.03897</td>
<td>64.07</td>
<td>0.24</td>
</tr>
<tr>
<td>0.85R</td>
<td>7.14</td>
<td>950</td>
<td>0.7734</td>
<td>0.04025</td>
<td>54.59</td>
<td>0.31</td>
</tr>
<tr>
<td>0.7R</td>
<td>7.14</td>
<td>950</td>
<td>0.88</td>
<td>0.04212</td>
<td>45.14</td>
<td>0.34</td>
</tr>
<tr>
<td>0.55R</td>
<td>7.14</td>
<td>950</td>
<td>1.0478</td>
<td>0.04535</td>
<td>35.74</td>
<td>0.39</td>
</tr>
<tr>
<td>0.4R</td>
<td>7.14</td>
<td>950</td>
<td>1.3409</td>
<td>0.05037</td>
<td>26.45</td>
<td>0.43</td>
</tr>
</tbody>
</table>

In this study, the turbine is three blades windmill, the total torque is three times that of a single blade, the overall TQ calculated is 0.171 (kgf·m).

The power $L = TQ \times \omega \times \frac{9.81}{1000} = 0.171 \times 99.48 \times \frac{9.81}{1000} = 0.167$ (kW).

The energy of the ideal wind is as follows:

$$P_W = \frac{1}{2} \rho AV^3$$

ρ: air density 1.229kg/m³.
A: area of the blade rotating
V: wind speed [m/s]

Then compare with the power of idea wind as shown in above equation to get the efficiency $\eta$

$$\eta = \frac{L}{P} = \frac{0.167}{0.242} = 68.9\%$$

The powers of different wind speed of design of this study are shown in Table 2.

Table 2. Different wind speed power comparison table.

<table>
<thead>
<tr>
<th>Wind speed V(m/s)</th>
<th>Rotating speed n(rpm)</th>
<th>Wind power P(kW)</th>
<th>TQ(kgf·m)</th>
<th>L(kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>3800</td>
<td>15.498</td>
<td>2.737</td>
<td>10.684</td>
</tr>
<tr>
<td>12</td>
<td>2850</td>
<td>6.538</td>
<td>1.539</td>
<td>4.507</td>
</tr>
<tr>
<td>8</td>
<td>1900</td>
<td>1.937</td>
<td>0.684</td>
<td>1.335</td>
</tr>
<tr>
<td>4</td>
<td>950</td>
<td>0.242</td>
<td>0.171</td>
<td>0.167</td>
</tr>
<tr>
<td>1</td>
<td>237.5</td>
<td>0.004</td>
<td>0.011</td>
<td>0.003</td>
</tr>
</tbody>
</table>
In order to compare the efficiency of this work, the efficiency of traditional windmill with the same diameter as the collector is compared. The calculated power $P$ is $0.039\,\text{kW}$ and torque is $0.158\,\text{kgf} \cdot \text{m}$ and the efficiency is 0.58. The wind speed is $4\,\text{m/s}$ and the tip speed is 8.913.

**Model Set Up**

Since the universal wind collecting device and the wind energy concentration and wind energy conversion device we designed are quite large in actual size, it is costly to actually make a prototype. Therefore, this work presents each function in the form of a model. Figure 6 shows the model. The model components is build by using a 3D printer, which is coupled with bearings and generators. This model is connected to the meter to see its power generation function. The operation of the model can be found that the duct rotates along the wind direction and the opening condition of the pressure relief valve when the wind speed exceeds the working wind speed of the turbine. Different wind speeds have different opening size. The model can fully demonstrate that the functions claimed in this work can be achieved.

![Figure 6. Model build by 3D printing.](image)

**Conclusion**

The goal of this study is to design small-sized windmills with less noise and higher energy efficiency than ordinary windmills. It can be used both in homes or buildings, and the consumption of transmission can be greatly reduced due to the proximity of users. The innovation of the work are:

1. Design a high-efficiency air-receiving duct. The air inlet of this duct has a mechanism that can rotate with the wind direction, so that the air inlet always faces the wind direction, thus having the largest air inlet surface. After the wind enters the pipeline to change the direction, it passes through a a turbine with a nose on the center shaft uses the space between the nose and the wall to concentrate the airflow oncece more and direct it close to the turbine blade tip, allowing the turbine to generate a large torque and more effectively receive the wind energy. The efficiency is 1.16 times that of traditional windmills.

2. Open a pressure relief valve at the right place of the air duct. When the wind is not strong, the valve is closed. When the wind is strong, the valve slowly opens to adjust the air volume entering the turbine. By doing this the turbine can generate electricity under the wider wind speed range than the typical windmill (usually windmills use wind ranges from $4\,\text{m/s}$ to $16\,\text{m/s}$, and the wind speed range in this study is about $2\,\text{m/s}$ to $20\,\text{m/s}$).

3. The present study is suitable for installation on the roof of each building.
References

