On Some Aspects of a Newly Designed Rotor using Convergent Nozzles

Shikha, T.S. Bhatti and D.P. Kothari

Abstract—The paper introduces a new concept of amplifying the wind speed before it comes in contact with the blades of a newly designed rotor by using a convergent nozzle. Instead of using large central station power plants, these new rotors can be most conveniently built in smaller units appropriate for individual load requirements. The importance of the work is high especially due to the current trend towards distributed or dispersed generation. Another effort has been made to analyse the optimum nozzle dimensions for a better performance of the system. A research program involving wind tunnel tests of five different nozzle models has also been conducted. The length and the outlet area of the nozzle were changed periodically to see their effect on the increase of wind speed. The variation of the output speed with different values of input wind speed, different input areas of nozzle and different lengths of nozzle have been outlined in the paper.

Index Terms: Wind energy, wind energy systems, convergent nozzles, vertical axis wind turbines.

I. INTRODUCTION

Wind technology has been greatly improved during the time, but the available technical know-how is not yet adequate to develop reliable Wind Energy Converting Systems (WECS) for low wind speeds. In spite of a few indigenous efforts, the developments of WECS working at low wind speed of 2-5 m/sec remain unfulfilled. This issue continues to be a matter of great concern for the developing countries.

A suggested option is the use of wind to provide electricity to areas not served by the power grid as distributed or dispersed generation. Instead of using large, central station power plants, wind plants can be most conveniently built in smaller units appropriate for individual loads and requirements in rural areas e.g. homes, businesses etc. The only hindrance is the average wind speed, which is generally low in most parts of the country. The new rotor using concentrating nozzle has been proposed for low wind speed areas. These wind turbine units using many small generators of 2-50 MW can be situated at various strategic points where wind speeds are low, so that each provides power to a small number of nearby consumers. Their major advantage is their modularity and portability. Also, they exploit the benefits of mass production. Being well matched in scale to those modest-sized jobs, they are uniquely portable, flexible, diversifiable, controllable, and accountable to end-users. But the most powerful logic behind them is that they avoid many of the hidden costs of centralization. Centralised electricity generation was based on the reasonable, sounding proposition that the bigger the power plant, the cheaper the capital cost per kilowatt and the higher the efficiency. This is however, no longer true [1]. For developing countries in Asia, it will be economical to have such units installed rather than big units of 500 MW or so.

The transmission and distribution losses have become an important issue for a poor economy of the third world. Generating power closer to where it's used ideally reduces not only transmission and distribution distances but also huge T and D losses.

These small wind systems are destined to meet the growing energy needs in the rural areas of the developing countries for promoting decentralised and hybrid development so as to stem growing migration of rural population to urban areas in search of better living conditions. The central grid has not yet reached many rural areas and is not likely to reach in near future and hence their only hope is these units.

Some of the biggest benefits, though hard to measure in dollars, are environmental and social ones. Interest in this subject is finally catching up with its importance. There's only one thing missing and that is synthesis. As volume of production of renewables increases, unit costs will come down, making them cost-effective in even more situations, and hastening the inevitable transition from an economy based on fossil fuel and nuclear power to one powered by the wind or sun [2] and [3].

II. THE NEW ROTOR – A PROMISING ONE

Although vertical axis wind turbines have been neglected till now, they can prove to be very promising as in the case of the new rotor designed.

Principle of Operation

This new rotor consists of six half cylinders whose axes are offset relative to one another. Air striking one blade is directed through the separation between the two halves of the blades and onto the other blade. To understand the exact operating principle of this turbine, a small two-bladed model was fabricated, placed and studied outside the wind tunnel. As can be seen from the Fig. 1, the force exerted by the wind is different on convex and concave parts of the turbine. In addition to this, the rotor is subjected to an aerodynamic couple caused by the deflection of air stream through 180° by the blades. Thus the rotor is subjected to a negative torque and the turbine does not work efficiently.

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To avoid the negative torque, the best possible option can be the use of a convergent nozzle. Thus a new model of a two-bladed rotor was fabricated using a convergent nozzle as shown in the Fig. 2 (a). The nozzle in this case performs two functions. It amplifies the wind speed and prevents the negative torque, acting as a barrier for wind striking on concave part of the blade {shown by dotted lines in Fig. 2 (a)}.

In a different condition when the blades of the turbine align with the wind direction as shown in the Fig. 2 (b), it can be seen that almost no aerodynamic couple is produced. In the first position, maximum torque is produced but in the second position no or very less torque is produced, as can be concluded after comparing the two positions in the Fig. 2. Most of the air thus passes freely without producing any torque.

To minimize this effect, a small model with four blades was fabricated as shown in Fig. 3. The testing was conducted outside a wind tunnel under atmospheric conditions. More speed is attained in case of four blades, because the negative torque effect is very less as can be seen from the figure.

Still a small amount of concentrated or amplified air passes without producing any torque. Thus came the idea of fabricating a six-bladed rotor as shown in Fig. 4. The functioning of the rotor was checked practically outside the wind tunnel to ensure that it nullifies the escape of amplified air and proved to be in good working order. Also the negative torque effect is minimized and the rotor worked very efficiently.

The swept area of the rotor in all the four models was kept the same. The current design aims at fulfilling the basic requirement of using every bit of air amplified by the nozzle. In this model, the speed of the rotor further increases. Wind speed was measured with a digital anemometer placed in the same relative position to the turbine. To ensure that six-bladed rotor is the optimum design, other models with eight and ten blades were also fabricated. The rotor does not work efficiently with further increase in the number of blades. This is due to the distortion and interference of wind profile passing through a reduced space between the blades. Of all the fabricated models, the six-bladed rotor worked most efficiently. It should be emphasized that these results are based on the practical analysis only.
III. ANALYSIS OF NOZZLE DIMENSIONS

By using a convergent nozzle the rotor speeds can be significantly increased, thus increasing the power coefficients. Also the rotor diameters can be decreased thus reducing the weight of the rotor. Thus the nozzle dimensions are of paramount concern and the nozzle should be designed in such a manner that it performs the amplification of wind velocity with minimum possible loss.

1) Important Parameters

The performance of nozzle depends mainly on two main parameters, inlet to exit area ratio and the length of the nozzle. To find out the optimum dimensions of the nozzle, five small nozzle models were fabricated and the testing was conducted outside a wind tunnel with controlled wind velocity at the inlet and the outlet left open to the atmosphere. It should be evident that the wind tunnel is simply a channel with controlled velocity capability exhausting to the atmosphere. Also the inlet area of the fabricated nozzle models was kept the same as the outlet area of the wind tunnel. These are variable dimension nozzles whose lengths could be varied for getting results. Different lengths of the nozzle were selected to see their effect on the increase of wind speed. Simultaneously, the outlet area of the nozzle was changed periodically along with the inlet speed. The dimensions of these models are given in Table 1.

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Inlet Area ( (A_1) )</th>
<th>Outlet Area ( (A_2) )</th>
<th>( A_2/A_1 ) (Ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>50 x 45</td>
<td>7.5 x 45</td>
<td>0.15</td>
</tr>
<tr>
<td>2.</td>
<td>50 x 45</td>
<td>12.5 x 45</td>
<td>0.25</td>
</tr>
<tr>
<td>3.</td>
<td>50 x 45</td>
<td>17.5 x 45</td>
<td>0.35</td>
</tr>
<tr>
<td>4.</td>
<td>50 x 45</td>
<td>22.5 x 45</td>
<td>0.45</td>
</tr>
<tr>
<td>5.</td>
<td>50 x 45</td>
<td>27.5 x 45</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Notation:

\[ L \] - Length of the nozzle (cms),
\[ V_1 \] - Inlet wind velocity at the nozzle (m/s),
\[ V_2 \] - Outlet wind velocity at the nozzle (m/s),
\[ V_r = V_2/V_1 \] - Amplification of wind velocity (Ratio of outlet to inlet wind velocity at the nozzle),
\[ A_1 \] - Inlet area of the nozzle \( (cm^2) \),
\[ A_2 \] - Outlet area of the nozzle \( (cm^2) \),
\[ A_r = A_2/A_1 \] - Ratio of outlet to inlet area of the nozzle,

2) Preliminary Results

A calculated average amplification rate of wind velocities for different nozzle models and different lengths of nozzles are shown in Table II.

<table>
<thead>
<tr>
<th>Model No.</th>
<th>( A_r ) (Ratio)</th>
<th>( L = 80 ) cms</th>
<th>( L = 55 ) cms</th>
<th>( L = 25 ) cms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.15</td>
<td>2.56</td>
<td>3.70</td>
<td>1.97</td>
</tr>
<tr>
<td>2.</td>
<td>0.25</td>
<td>2.00</td>
<td>2.50</td>
<td>1.47</td>
</tr>
<tr>
<td>3.</td>
<td>0.35</td>
<td>1.50</td>
<td>1.73</td>
<td>1.11</td>
</tr>
<tr>
<td>4.</td>
<td>0.45</td>
<td>1.10</td>
<td>1.10</td>
<td>1.01</td>
</tr>
<tr>
<td>5.</td>
<td>0.55</td>
<td>1.02</td>
<td>1.03</td>
<td>1.01</td>
</tr>
</tbody>
</table>

2.1) Effect of length of nozzle

As can be seen from the Table 2 the length of the nozzle is a very important parameter and cannot be neglected while designing the nozzle. The nozzle should neither be too long nor too short. When the length of the nozzle is 80 cms, the wind velocity increases considerably. But the best results are obtained with 55 cms long nozzle where the increase in wind velocity is the maximum. When the length is further decreased to 25 cms, the results were found to be very poor, indicating that too short a nozzle doesn't work efficiently. Thus the optimum length of the nozzle is necessary for obtaining the best results.

2.2) Effect of inlet to outlet area ratio

Model 1 \((A_2/A_1 = 0.15)\) gave the best results showing a velocity increase of 2.0-3.7 times depending upon the length of the nozzle. Model 2 \((A_2/A_1 = 0.25)\) showed 1.5-2.5 times increase in wind velocity. In model 3 \((A_2/A_1 = 0.35)\) the velocity increases from 1.1-1.7 times while model 4 \((A_2/A_1 = 0.45)\) and model 5 \((A_2/A_1 = 0.55)\) resulted in the worst results showing almost no increase in the wind velocity. Thus optimum area should be found out for the nozzle to work very efficiently. From here it can thus be concluded that both length and inlet to exit area ratio need to be optimized for getting the best possible results. The different curves of the results of the experiments conducted outside the wind tunnel are shown in Fig. 5 for comparison.

Fig. 5. Area versus velocity ratio
The results verify that the incorporation of a simple convergent nozzle allows the wind speed to increase to a great extent. It can be observed from the curves in Fig. 5 that the maximum amplification is 3.7 times of the input wind velocity when (a) the outlet area is reduced to about six times of the inlet area and (b) the length of the nozzle is 55 cms. Further reduction in outlet area and increase in the length of the nozzle did not increase the wind velocity. Apart from these tests, some additional tests were needed to check the variation of amplification ratio and the exact behaviour of the nozzle when placed at different distances from the wind tunnel outlet.

IV. DISCUSSIONS

The basic reason behind the introduction of convergent nozzles is the prevention of negative torque. Amplification of wind velocity is an additional advantage. The factors that characterise and determine the final performance of the rotor are wind velocity at the inlet and the number of blades. The nozzle captures air from larger area and delivers it to the rotor, producing more power with a smaller rotor. Increasing the number of blades from two to six improves the efficiency of the rotor. A good balance has to be struck between the number of blades and optimised nozzle dimensions (length and inlet to exit area ratio) for achieving high efficiency and good performance of the system. Before testing of full-scale machines, there was a general belief that Horizontal Axis Wind Turbines (HAWT) were inherently more efficient [4] – [6]. Field experience has conclusively proved this assumption to be false. Vertical Axis Wind Turbines (VAWT) are every bit as efficient as HAWT's and, in fact for some cases even more efficient [7]. Use of nozzles with six-bladed rotor enhances the power coefficient, as power extraction is possible from larger area at low wind speeds. A point of notice is that, although the experiments have been conducted by using one nozzle only, it is, however, possible to construct more nozzles so as to cover the turbine from all sides in case of change in wind direction. But for the major portion of the year, the wind blows in one direction only. So constructing more nozzles requires much more amount and maintenance and is not a suggested option.

VI. ACKNOWLEDGMENTS

The authors gratefully acknowledge the Council of Scientific and Industrial Research grants (CSIR Complex, NPL Campus, New Delhi) and the Department of Science and Technology (New Delhi) for the financial assistance and the facilities offered to carry out this work.

VII. REFERENCES