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# Numerical Analysis of Venturi Ducted Horizontal Axis Wind Turbine for Efficient Power Generation

**Chandan D. Chaudhari**[1], **Sainath A. Waghmare**[2], **and AshishP. Kotwal**[3]

[1]*Dept. of Mech. Engg.,DattaMeghe College of Engg., Airoli, Navi Mumbai,*

,[2,3]*Dept. of Mech. Engg.,LokmanyaTilak College of Engg., Koparkhairane, Navi Mumbai*,

chaudhari.chandan22@gmail.com, ashish.kotwal@outlook.com, sainathwaghmare1990@gmail.com

***Abstract*—Recent developments are carried out to enhance the performance of horizontal axis wind turbines (HAWT). In these developments a low pressure region was created behind the wind turbine blades enclosed by diffuser or shroud. In this paper the venturi effect was used to concentrate the air flow to the turbine blades with convergent section, which increases the velocity at turbine blades and low pressure region created behind the blades by divergent section, whereas turbine was mounted at the throat section. ANSYS FLUENT 14.0 was used to study the behaviour of air flow through venturi and results were compared with bare HAWT. The aim of the project is to reflect an idea of wind power plant in the urban areas where wind velocity is low. The increased velocity of wind resulted in significant improvement in the kinetic energy hence power output of turbine.**

***Keywords*— Venturi, HAWT, Turbine blades, Venturi effects, CFD analysis**

## I. INTRODUCTION

Wind power plants are established mostly in open grounds to get open air stream of air. An open air stream contains more potential energy than kinetic energy. This available kinetic energy was utilised by bare wind turbines to generate power. This paper focuses on concentration of wind on HAWT blade which results into increment of wind velocity hence kinetic energy. To accomplish this purpose the phenomenon venturi effect was used. A venturi has three regions i.e. contraction, throat and divergent section, which creates differences in cross section areas of a tube or pipe. This difference in cross section areas results in pressure difference in each region of venturi. Based on the *Bernoulli*and *Venturi*principles, the wind speeds will increasedepending on the difference in cross sections.Since the only energy injected in the system iswind, and mass flow and energy balances, it isthe pressureenergy that is converted toadditional kinetic energy [1]. This process allowsthe WTG installed in the Venturi section to haveaccess to much larger kinetic energy of the wind,and thus be able to generate same or more power using smaller turbines[1].

## II. VENTURI EFFECT

The Venturi effect is named after Giovanni Battista Venturi (1746–1822), an Italian physicist. An equation for the drop in pressure due to the Venturi effect may be derived from a combination of *Bernoulli's principle* and the *continuity equation*.

$$P + \tfrac{1}{2}mV^2 + \rho g\,h = \text{constant} \qquad (1)$$

Using Bernoulli's equation in the special case of incompressible flows (such as the flow of water or other liquid, or low speed flow of gas), the theoretical pressure drop at the constriction is given by:

$$P1 - P2 = \rho/2 * (V^2_2 - V^2_1) \qquad (2)$$

And,

$$A1 * V1 = A2 * V2 \qquad (3)$$

Where:
A = area,V = velocity,
ρ = density of fluid,g = acceleration constant,
h = height,P = fluid pressure.

The acceleration of the airflow was achieved with the use of a converging duct. This is illustrated in the diagram of Fig.1.

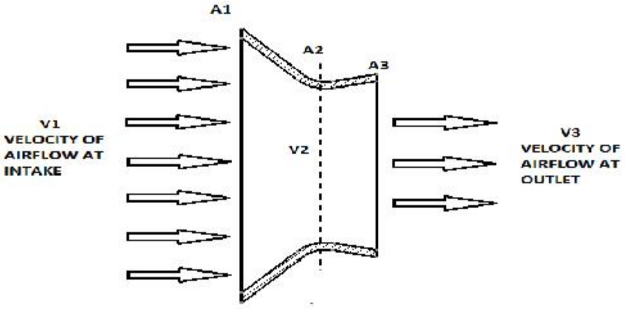

Fig.1: Illustration of the venturi maintaining continuity equation

Therefore,

$$V2 = (A1 * V1)/A2 \quad (4)$$

$$V2 = [\ (\pi/4) * D1^2 * V1] / (\pi/4) * D1^2 \qquad (5)$$

For all wind turbines, wind power is proportional to wind speed cubed. Wind energy is the kinetic energy of the moving air. The kinetic energy of a mass m with the velocity V is,

$$E_{kin} = \tfrac{1}{2}\, m\, V^2 \quad (6)$$

The mass of air, m can be determined from the air density ρ and the air volume V according to,

$$m = \rho\, V \quad (7)$$

Then, $E_{kin,\ wind} = \tfrac{1}{2}\, \rho\, V\, V^2$ (8)

Power is energy divided by time. Considering a small time, Δt, in which the air particles travel a distance s = v Δt to flow through. Multiplying the distance with the rotor area of the wind turbine, At, resulting in a volume of

$$\Delta V = At\ V\ \Delta t \qquad (9)$$

whichdrives the wind turbine for the small period of time. Then the wind power is given as,

$$P_{wind} = \frac{E_{kin,wind}}{\Delta t} = \frac{\Delta V\, \rho\, V^2}{2\Delta t} = \frac{\rho\, At\, V^3}{2} \qquad (10)$$

The wind power increases with the cube of the wind speed.According to the venturi effect as discussed earlier in this paper that high velocity zone is the throat area. Hence the turbine was mounted in this zone to utilise the high kinetic energy. Fig. 2 showing turbine blade inserted into throat area of venturi.

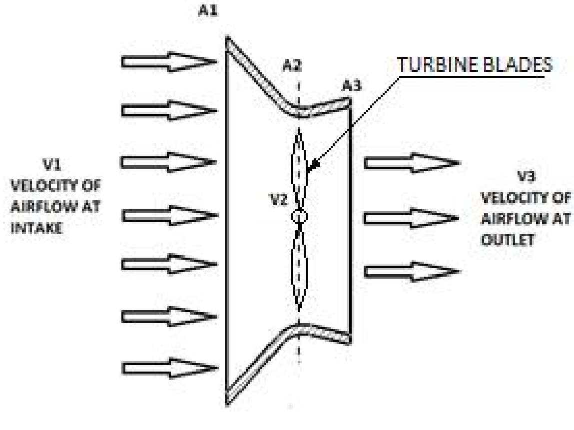

Fig.2: Turbine blade inserted into throat area of venturi

## III. VENTURI DESIGN AND MODELLING

The venturi is modelled in CATIA V5 as per the existing design by I.H. Al-Bahadly and A.F.T. Petersen [2] with modified curves.

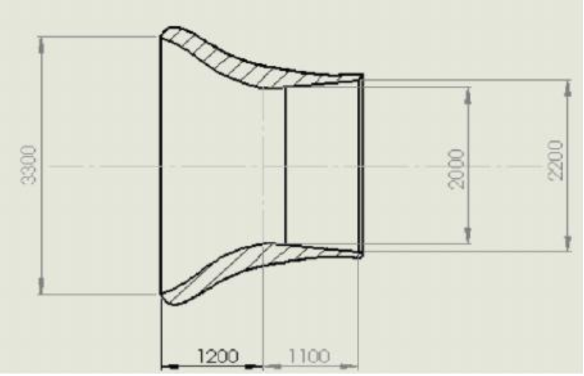

Fig.3: Turbine blade inserted into throat area of venturi [2]

The velocity of air at throat section is,

$$V2 = [\ (\pi/4) * D1^2 * V1] / (\pi/4) * D1^2$$
$$= [\ (\pi/4) * 33^2 * 4] / (\pi/4) * 33^2$$
$$\underline{V2 = 10.89\ m/s}$$

The velocity of air at exit is,

$$V3 = [\ (\pi/4) * D2^2 * V2] / (\pi/4) * D2^2$$
$$= [\ (\pi/4) * 20^2 * 10.89] / (\pi/4) * 20^2$$
$$\underline{V2 = 9\ m/s}$$

## IV. CFD ANALYSIS OF VENTURI

CFD techniques are used to study the behaviour of air flow through venturi with and without turbine. Conditions are considered as per International Standard Atmosphere (ISA) and Normal Temperature and Pressure (NTP) conditions. Inlet velocity was taken as 4 m/s in X-direction.

The CFD analysis was carried out on venturi without turbine. Fig. 4 and 5 shows velocity, pressure zones. As stated earlier that the velocity would increase at throat section indicated by red colour and its magnitude was shown by scale.Similarly in pressure profile, it decreases in throat area shown in fig. 5.

CFD analysis on with turbine blades was carried to determine exact velocity available on turbine blades and their results are shown in fig. 6 and 7 with velocity and pressure plot respectively. In both the cases, a low pressure region was created in upper part of diffuser end which is responsible to draw more air from venturi. Its results increment in velocity throughout the venturi section.

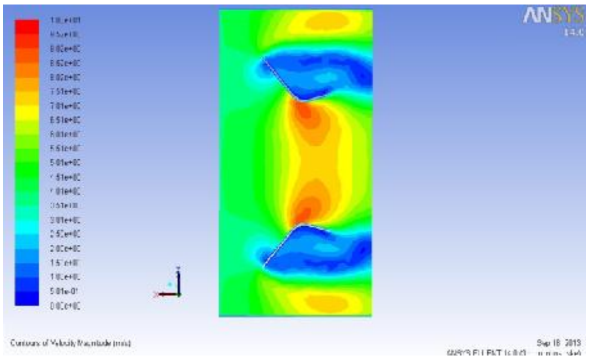

Fig.4: Velocity profile inventuri without turbine blades

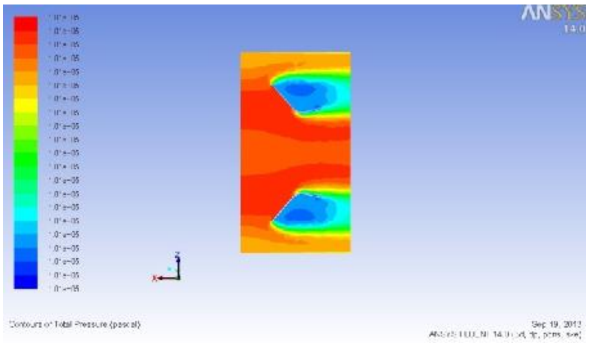

Fig.5: Total Pressure profile in venturi without turbine blades

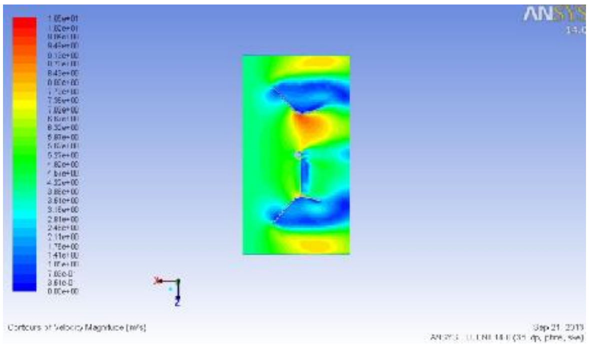

Fig.6: Velocity profile in venturi with turbine blades

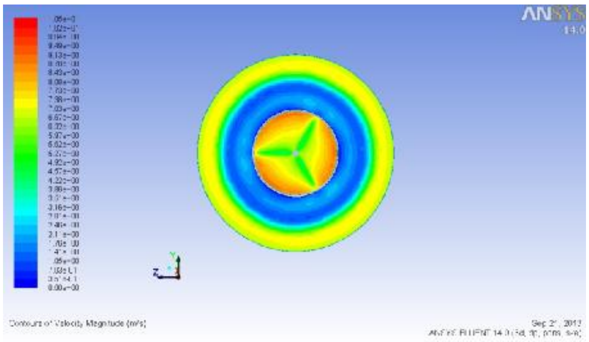

Fig.7: Velocity profile in venturi with turbine blades in Z-Y plane

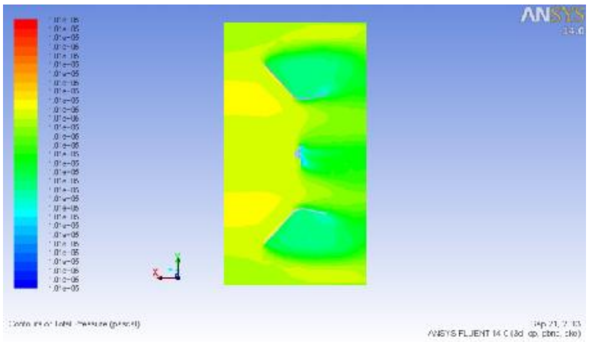

Fig.8: Total Pressure profile in venturi with turbine blades

## V. RESULT DISSCUSSION

Fig. 9 and 10 shows the velocity and pressure profiles respectively at a cross sectional area inside the *Venturi*. It was noted that the average velocity was raised to more than 7 m/s, while the maximum velocity was increased to more than 9 m/s, speed ratio of more than 2.25

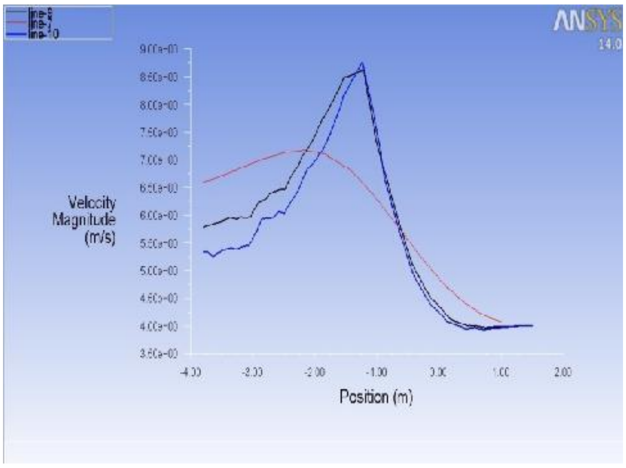

Fig.9: Velocity plot without turbine blades

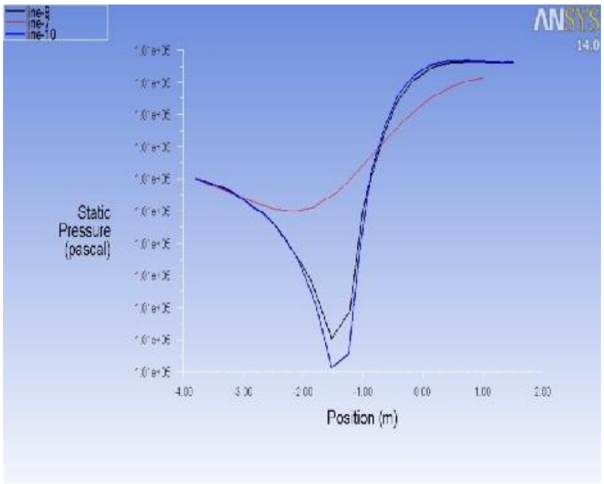

Fig.10: Static Pressure plot without turbine blades

The accurate result can be obtained by introducing the turbine blades into the venturi. Fig.11 and 12 shows velocity and pressure plots. Here the average velocity obtained was more than7 m/s and maximum was 9.75 m/s.

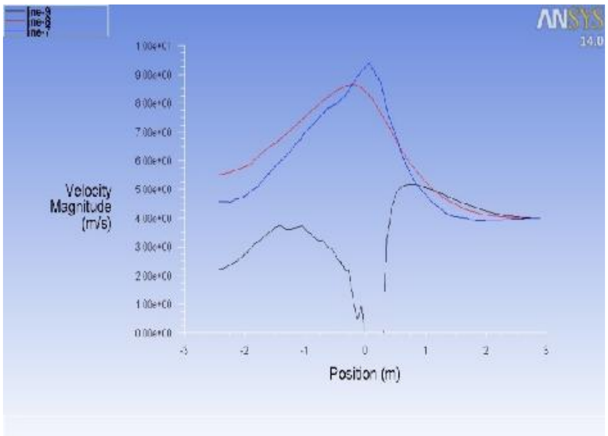

Fig.11: Velocity plot with turbine blades

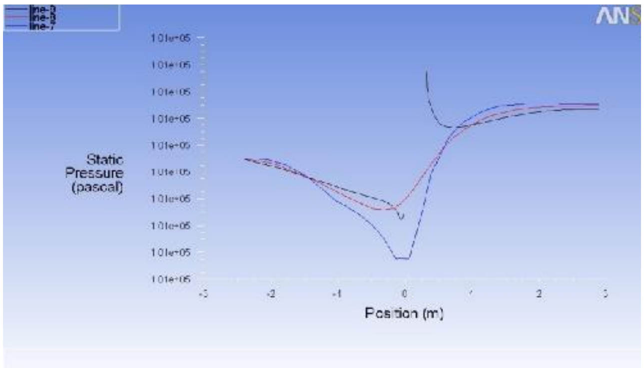

Fig.12: Static pressure plot with turbine blades

## VI. CONCLUSION

The exiting design of venturi was utilised for wind study. The results from CFD analysis are found nearly same as the analytical calculations. The result shows that the average velocity in the venturi section was found to be 1.75 times, whereas maximum velocity achieved was 2.5 times of inlet velocity of air.Since power is proportional to cubic power of wind speed, 60% increase in wind speed, means power output is increased by 5 times.

## VII. FUTURE SCOPE

It was restricted up to the parameter study and find constant parameter, respectively. Therefore a wide field for further investigations already exists only for the parameter study itself. It is possible to work this concept with real life prototyping and verify the results with theoretical output.

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