Performance Improvement of Modified Omnidirectional Ducted Wind Mill

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Abstract— Multi physics simulation has progressed significantly in the recent years so that predictions of flow around and inside complex geometries are now possible. In the present work, simulations are used to evaluate a highly acclaimed innovative wind power generation system known as omnidirectional wind turbine. The model was developed using ANSYS 16. The fluid dynamic modules were employed. The objective was to validate that this patented technology significantly outperforms traditional wind turbines and it delivers superior power output. A full scale model is built to verify laboratory and field test data and to utilize the validated model as an effective design tool during product development period. The computations involved cases with different incoming wind directions and changes in the intake geometry. The results are compared with those obtained by using another CFD package. The results illustrate capturing, accelerating and concentrating wind. Increased wind velocities result in significant improvement in the power output. Here, grid independency test is also done.

Key words: Performance Improvement, Concentrating Wind

I. INTRODUCTION

Wind energy conversion systems have existed for more than 3000 years. Since the appearance of the ancient Persian vertical axis windmills 3000 years ago, many different types of windmills have been invented. Initially, wind energy was used to induce a function, such as moving boats using sail, cooling houses by circulating outside air, running machinery in farms, and even small production facilities. In late 1800s and early 1900s, conversion of wind energy to electrical power marked a turning point for the wind power generation industry. The review in Ref. [1] provides a very good description of its historical development. Due to energy crises and changes in the political and social climates, wind turbines started to rapidly spread across the globe in the last three decades. However, wind power is far from reaching its full potential.

II. PROBLEM IDENTIFICATION

The INVELOX system shown in Figure 1 is modeled in this work. Capture, accelerate, concentrate are the three words express the essence of INVELOX approach to wind power generation. The name INVELOX was born of this dedication to increasing the velocity of wind, and what the technology promises—energy that is affordable, abundant, safe, and clean—is nothing short of revolutionary. The fundamental innovation of the INVELOX system is that it eliminates the need for tower-mounted turbines. It's not merely a refinement of existing technology; it is, rather, a deep rethinking of the problem. Instead of snatching bits of energy from the air as it passes through the blades of a rotor, it captures the source with a funnel and directs it through a tapering passageway that naturally accelerates its flow. Then this stream of kinetic energy is used to drive a generator that's installed safely and economically at ground level.

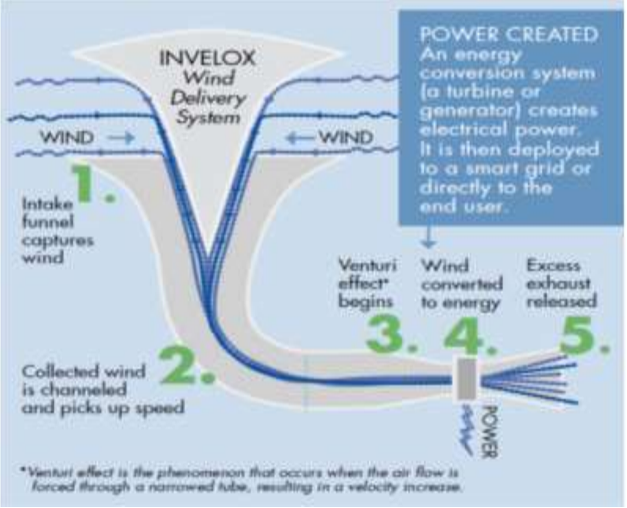

Fig. 1: Involex System

A. *Description of The INVELOX Delivery System*

The five key parts of INVELOX are shown in Fig. 1. These key parts are (1) intake, (2) pipe carrying and accelerating wind, (3) boosting wind speed by a Venturi, (4) wind energy conversions system, and (5) a diffuser. Control volume analysis for conservation of mass, axial and angular momentum balances, and energy conservation for inviscid, incompressible axisymmetric flows yields [6]:

1) *Continuity Equation*

$$\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho . V) = 0$$

Where,

∇ is the vector operator and can be described in Cartesian co-ordinates as

$$\nabla = i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z}$$

2) *Momentum Equations*

$$\frac{\partial(\rho u)}{\partial t} + \nabla \bullet (\rho . u . V) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + f_x$$

I II III IV V

$$\frac{\partial(\rho V)}{\partial t} + \nabla \bullet (\rho . v . V) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + f_y$$

$$\frac{\partial(\rho w)}{\partial t} + \nabla \bullet (\rho . w . V) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + f_z$$

Where,

u is the vector component of velocity in the x direction
v is the vector component of velocity in the y direction
w is the vector component of velocity in the z direction
$\tau_{xx}, \tau_{yy}, \tau_{zz}$ are normal stresses
$\tau_{xy}, \tau_{xz}, \tau_{yx}, \tau_{yz}, \tau_{zx}$, and τ_{zy} are shear stresses.

f_x, f_y and f_z are body force acting in the respective direction

3) *Energy Equation*

The equation for the principle of energy conservation or Energy equation for viscous flow is given by,

$$\partial/\partial t\ [\ \rho\ (e+v^2/2)\ ] + \blacktriangledown.[\ \rho\ (e+v^2/2)\ ] = \rho q + \partial/\partial x\ (k\partial T/\partial x) + \partial/\partial y\ (k\partial T/\partial y) + \partial/\partial z\ (k\partial T/\partial z) + \partial(up)/\partial x + \partial(vp)/\partial y + \partial(wp)/\partial z + \partial(u\tau_{xx})/\partial x + \partial(u\tau_{yx})/\partial y + \partial(u\tau_{zx})/\partial z + \partial(v\tau_{xy})/\partial x + \partial(v\tau_{yy})/\partial y + \partial(u\tau_{zy})/\partial z + \partial(w\tau_{xz})/\partial x + \partial(w\tau_{yz})/\partial y + \partial(w\tau_{zz})/\partial z + \rho fV$$

The fundamental characteristic of the INVELOX system is that it captures a large portion of free stream air flow and can do so in nearly any free stream locations with flow greater than 1 m/s. This increased mass flow rate carries energy per unit mass from the free stream which for inviscid fluids remains unchanged till it interacts with the turbine in the Venturi section.

III. BASIC CALCULATION

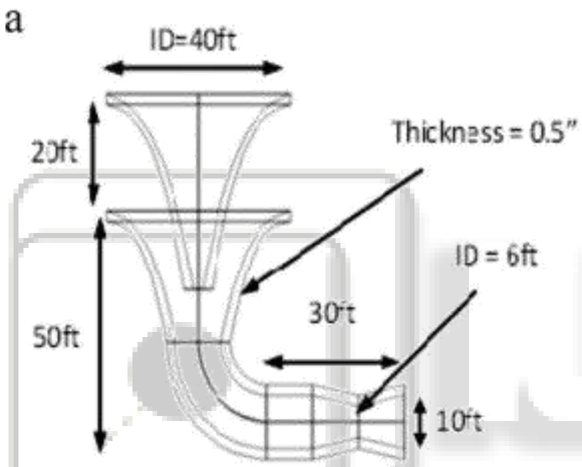

Fig. 2: Dimention Of The System

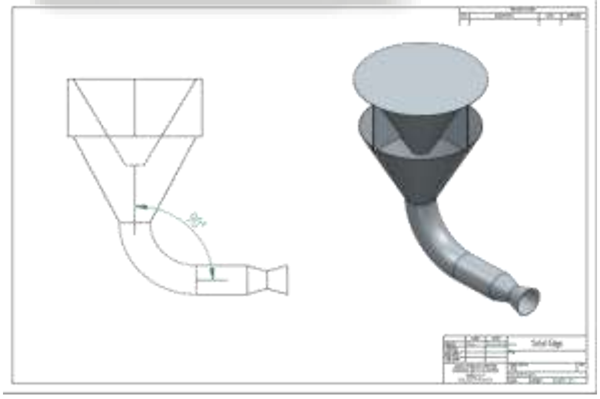

Fig. 3: Modeling Of The System

$Pa_1 - Pa_2 = ½\ \rho(V_2^2 - V_1^2)$

And,

$A_1 * V_1 = A_2 * V_2$

Here,

$D_1=4$ m $\quad D_2=1.6$ m

$A_1 = \pi/4 * D_1^2 \quad A_2 = \pi/4 * D_2^2$

$= 12.56$ m$^2 \quad =2$ m^2

In Ahmedabad annual average wind speed is measured around 4.51 m/sec so take the V_1=4.51 m/sec.

So,

$12.56 * 4.51 = 2 * V_2$

V_2=28.32 m/se

A. *Density*

$$\rho = \frac{Pa \times n}{R \times T}$$

$$\rho = \frac{101221 \times 29}{8.314 \times 293}$$

$$=1.205 \text{ kg/m}^3$$

The power calculate at the starting point of the system,

$$\text{Power} = ½ * \rho * A_1 * V_1^3$$
$$=½ * 1.293 * 12.56 * 4.51^3$$
$$=744.88 \text{ watt}$$

Power calculate at the venturi section,

Power (AT VENTURI)= $½ * \rho * A_2 * V_2^3$

$$=½ * 1.205 * 2.00 * 28.32^3$$
$$=27369.49 \text{ watt}$$

B. *Actual Power*

The ducted turbine has an estimated Cp of 0.41.

Therefore,

$P_T = ½ * \rho * A_2 * V_2^3 * Cp$

=27369.49×0.41

=11221.49 watt

=11.2 kw

C. *Actual Torque*

$$\Omega = \frac{2 \times \pi \times N}{60} \quad =62.8 \text{ rad/sec}$$

Tip speed ratio λ,

$$\lambda = \frac{R \times \Omega}{V} = \frac{R \times 2 \times \pi \times N}{V} = \frac{62.8 \times 0.8}{28.32} =1.77$$

Therefore the torque coefficient is,

$$C_T = \frac{Cp}{\lambda} = \frac{0.41}{1.77} = 0.23$$

To calculate torque,

$T_T = ½ * \rho * A_2 * V^2 * R * C_T$

$= ½ * 1.205 * 2 * 28.32^2 * 0.8 * 0.23$

=178.68 kg.m.sec-1

Hydraulic diameter,

$$D_h = 4\ A_2/\ Perimeter$$
$$= \frac{4 \times 2}{\pi \times 1.6} =1.59\text{m}$$

Reynold Number,

$$R_e = \frac{\rho\ V\ D}{\mu}$$
$$= V_2 \times D_h / \upsilon$$
$$= 28.32 \times 1.6 / 1.62 \times 10^{-4}$$
$$= 2.8 \times 10^5$$

Colebrook formula for the friction factor,

$$\frac{1}{\sqrt{f}} = -2 \log \left(\frac{e}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right)$$

here, e=roughness value(smooth concreet) $= 4 \times 10^{-5}$

$$\frac{1}{\sqrt{f}} = \frac{1}{0.69}$$

f=0.47

D. *CFD (Computational Fluid Dynamics) Models*

The dimensions and geometry of unidirectional INVELOX modeled. This model (INVELOX-12-02) uses double nested cone concept with 360-degree wind intake capability. This unit is scaled to fit a 1.8 m (6 ft) diameter wind turbine at the Venturi location, and to be erected to a height of 18 m (60 ft). Because INVELOX has no rotor/hub on the top, the height of the tower is measured from the center of the intake to the ground level. If the free stream wind speed is 6 m/s, the speed at the location of the turbine (Venturi) will be equal to 51 m/s. The intake is composed of two nested cones. The top cone is the guide directing wind into the lower cone. The intake of the INVELOX tower was also fitted with four fins oriented at 45 degree angle to flow direction as shown in Fig.3.

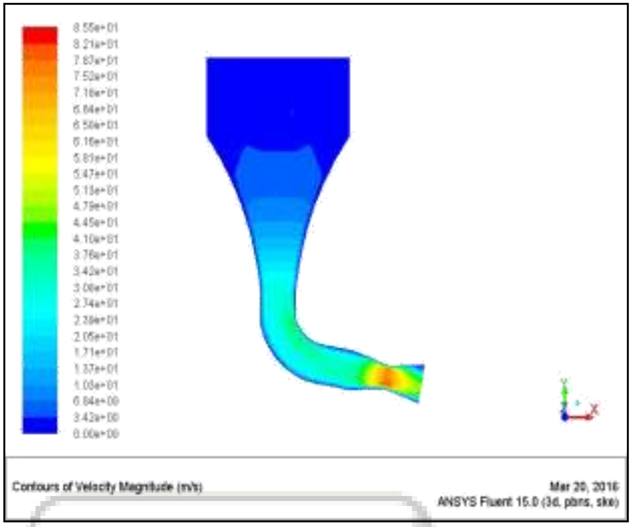

Fig. 3: Velocity Megnitude of the System

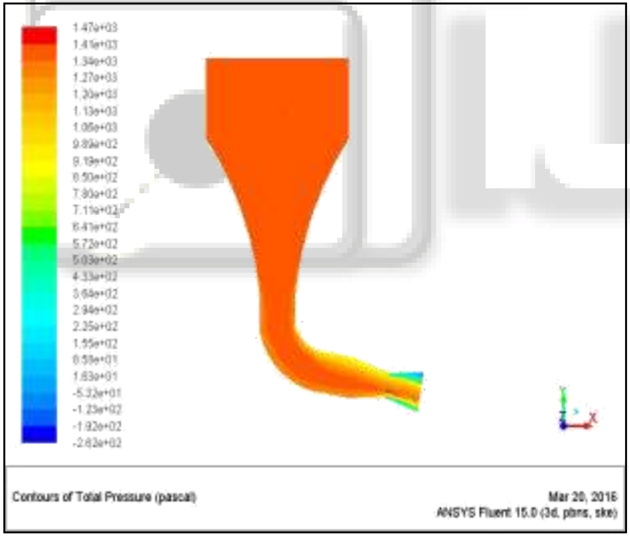

Fig. 4: Pressure Distribution of The System

IV. GRID ANALYSIS TETRAHEDRAL MESHING

Grid convergence is the term used to describe the improvement of results by using successively smaller cell sizes for the calculations. A calculation should approach the correct answer as the mesh becomes finer, hence the term grid convergence.

No	Case	Node	Element
1	120 degree	63413	324282
		91033	473446
		168160	895519

Table 1: Grid Analysis with Tetrahedral Meshing (120 angle)

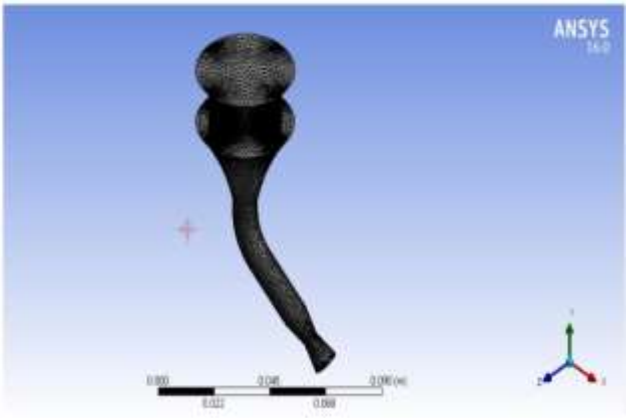

Fig. 5: Grid development of 120-degree system

However, we have developed an algorithm that diverges very little as the cell size is increased making it much easier to obtain the necessary accuracy, even on coarse grids. We have termed this ability to retain consistency across varying cell sizes as 'grid independence' or 'scaling', as the algorithm is attempting to find the same fundamental solution independent of either grid size or scale factor.

In this section we look at the three runs of the same problem but on very different grids. These show how well the software copes with a changing scale and how very close it is to having grid independence.

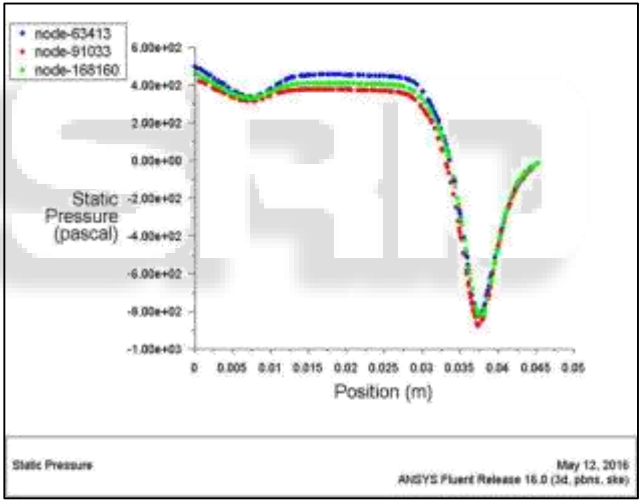

Fig. 6: Static Pressure Graph

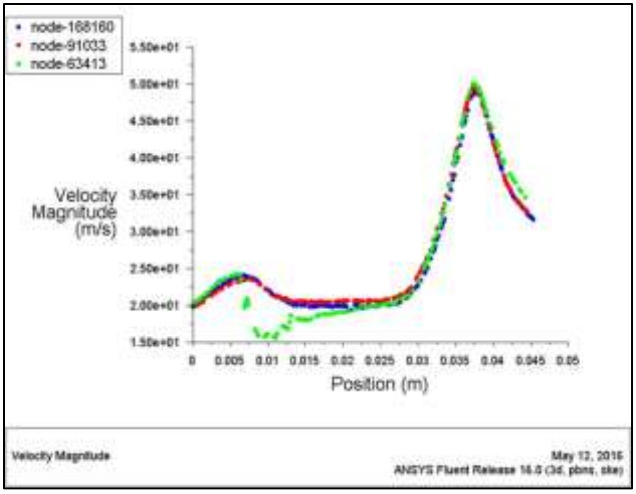

Fig. 7: velocity magnitude (m/sec)

Grid independent is associated with the accuracy or even rationality of numerical results. This paper takes twodimensional steady heat transfer for example to reveal the effect of grid resolution on numerical results. The law of grid dependence is obtained and a simple mathematical formula is presented. The production acquired here can be used as the guidance in choosing grid density in numerical simulation and get exact grid independent value without using infinite fine grid. Through analysing grid independent, we can find the minimum number of grid cells that is needed to get grid-independent results. Such strategy can save computational resource while ensure a rational computational result.

V. CONCLUSION

- From the literature review, I come to know that, Omni-directional wind turbine can capture a wind from the 360 degree (from all direction) and due to density of the air it forced to flow through the duct and further assembly.
- When wind capture at the nominal wind speed around 6.71 m/sec it convert into a high velocity wind with passing it into a venturi portion which is measured around 50 to 60 m/sec and subsequently increased a power output.
- After reviewing all research papers, I found that the extracted wind power P can increase by increasing the mass flow rate or total energy drop across the turbine.
- L-bow bend is resist speed of the wind larger than the higher angle duct such as 100, 120 degrees, low air friction can give up more speed and i want to perform CFD analysis of the system with this angles ducts and compared it with the existing L-blow duct for velocity and pressure distribution in the system.
- I perform 120-degree duct’s grid analysis, which gives the better result in 168160 nodes and around 895519 elements.

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