Guide Vane Height Effect on Performance of Sheer Wind Turbine

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Abstract- A sheer wind turbine is a new concept of wind energy harnessing technology that eliminates the disadvantages like huge size, swept area and bird species loss, noise pollution etc. of traditional turbine and provide power output with reduced cost. Its peculiarity is that it eliminates the tower loading turbines. The main advantages of sheer wind turbines are sucks the air omni-directionally and funnel is placed at the ground level where impact of the low velocity wind on the turbine causes energy generation thus it eliminates the disadvantages of traditional windmills like low turbine reliability, downtime issues, adverse environmental issues. The overall objective of this work is to model the system with different guide vane heights as 1.75m, 2m, 2.25m and 2.5m with throat diameters as 0.5m to 0.8m to understand actual fluid flow inside the INVELOX where the wind turbines are situated. Various computations are carried out to check the relation between wind direction and inside geometry of system through CFD simulation. The study shows it is possible to capture, accelerate and concentrate to obtain higher power output. And hence INVELOX is better way of harnessing wind energy any time any were.

Keywords – Guide vane height, Sheer wind, Invelox, Wind turbine

I. Introduction

Energy Production is most important issue of today's era. We have been using different kinds of energy in our day to day life. We have been using fossil fuels in the form of energy since 1700's. The industrial revolution of 18 century gave rise to use of substance based energy forms i.e. fossil fuels like petrol, diesel, gasoline, etc. These energy forms are easily accessible in nature. But even though being easily accessible these energy forms are available in limited amount and world is leading towards population explosion on other hand. Also they have some drawbacks like they are getting unaffordable day by day, and their emission leads to pollution, thus causing damage to ecosystem. And now from 1970 onwards we started facing energy crisis due to all these factors. Hence it was need of time to adopt new energy generation techniques.

1.1 Description of the INVELOX delivery system-

INVELOX stands for INcreased VELOcity. A new concept in utilizing the low speed wind is defined. INVELOX is the innovation of Daryoush Allaei supported by SHEERWIND in developing and installing for experimental purpose. 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.

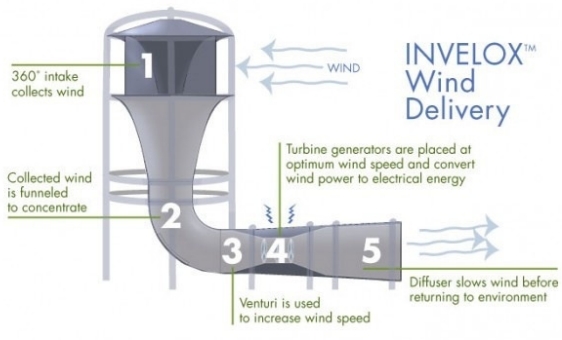


Figure 1. Schematic of the INVELOX wind delivery system (Source: Wind fair)

Control volume analysis for conservation of mass, axial and angular momentum balances, and energy conservation for inviscid, incompressible axisymmetric flows yields.

$$A\int \rho V.dA = 0; A\int ux\rho V.dA = T- A\int PdA.ex \qquad (1)$$

$$A\int ru\theta\rho V.dA= Q; A\int [P/\rho +1/2[V]2] \rho V.dA = P \qquad (2)$$

where V= (ux, ur, uq) is the velocity vector in the axial, radial, and azimuthal direction, respectively; r is the radius; ρ is the density of air; A denotes the outward-pointing area vector of the control surface; ex is the unit vector in the x direction; p is the pressure; T is the axial force (thrust) acting on the rotor; Q is the torque; and P is the power extracted from the rotor. It is obvious from the above relation that the extracted wind power P can increase by increasing the mass flow rate $A\int \rho V.dA$ or the total energy drop $\int[P/\rho +1/2[V]2]$ in out across the turbine. 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 given by e = [P/ρ +1/2[V]2] which for inviscid fluids remains unchanged till it interacts with the turbine in the Venturi section. INVELOX passively converts the existing kinetic and potential/ pressure energy of wind to higher kinetic energy 1/2 [V]2 that can more effectively be converted to mechanical rotation of a turbine. Along any part of the INVELOX tower of constant crosssection the velocity remains the same and therefore there is no kinetic energy drop across the turbine. Thus, the extracted power is given by P = ∫ (ρ V) ρ V.dA which can be approximated by the P =ηQΔA where Q is the increased volumetric flow rate, Δp is the pressure drop across the turbine and η is its efficiency. INVELOX allows a much lower cut-in speed because it can increase wind speed at the location of the turbine. Most of the ducted turbine companies in USA and Europe, Japan, and China have limited their product lines to small wind power (below 50 kW). The most successful ones are those that limited the power below 5 kW. It is true that INVELOX falls under general area of ducted turbines. But it has distinct differences that make it financially viable and performance wise superior to the other ducted turbines and traditional horizontal axis wind turbines.

1.2 Key features of INVELOX

1) The intake and turbine are decoupled. This means the intake size may be adjusted while keeping the turbine as small as necessary depending on the required speed ratio and environmental conditions.

2) The above decoupling of intake and turbine location allows the WTG (Wind Turbine Generator) be mounted at the ground level and thereby reduce O&M.

3) Decoupling of the intake and Venturi, where the turbine is installed, allows designing INVELOX with speed ratio of 6 or higher. This allows operating at high wind speeds and thus generating a lot more power with smaller blades while utilizing a much more efficient generators operating at higher speeds.

4) Smaller blades operating at higher wind speeds results in 85% smaller blades that results in cost savings in material, manufacturing, transportation, and installation.

5) The intake designed to be Omni directional and thus no need for huge bearing and motors to turn the intake in the direction of wind.

6) INVELOX can be designed with a power rating of 500 W to 25 MW. All that matter is how much air is captured

II. Literature Review

Daryoush Allai, Yiannis Andreopoulos [1] compared the cfd computations of two different models of invelox ducts and concluded the experimental results. Lilley And Railbird [2] performed a theoretical study to obtain the gain of generated power output from a fully ducted land type wind turbine that was 65 % of the maximum power output of the ideal bare wind turbine. Igrae [3] used a blowing at shroud intake and airfoil shaped ring-flap at exit of diffuser as two techniques to prevent flow separation and increase power generation. The blowing increased the output power by 20%, while using airfoil shaped ring-flap produced an increase in power by 65%. Foreman [4] investigates a technical and economic study about diffuser augmented wind turbine ‘‘DAWT”. The study obtained significant power augmentation from DAWT approaching twice of power generated by bare wind turbine. The increase of power was produced due to low pressure at diffuser exit that pumps much larger amounts of air through a DAWT than a conventional wind turbine. Gilbert [5] studies the parameters that affect on the performance of the diffuser system and examined it in wind tunnel. Their first generation of DAWT provided about twice the power of a conventional wind energy conversion system ‘‘WECS” with the same turbine diameter and wind velocity and Maximum augmentation ratio reaches 3. Phillips [6] investigates theoretical, numerical and experimental tests on Vortec 7 wind turbine and compared it with previous experimental work. It was obtained that the CFD agreed quite well with field measurements. Many of the field results also agreed with the previous experimental result. Hansen [7] compared the CFD computations of a bare turbine with the theoretical expression for the power coefficient as a function of the thrust coefficient. The actuator disk approach is sufficient for modeling the rotor of wind turbine and also was seen that the Betz limit can be exceeded with a ratio corresponding to the relative increase in mass flow rate through the rotor when using diffuser for rotor. Abe And Ohya [8] study the flow fields around flanged diffuser using CFD to develop small-type wind turbines under 1.5 kW. Comparison of the computed results with the corresponding experimental data shows that their calculation had the capability of providing reasonable predictions for the complex turbulent flows. It was shown that the performance of a flanged diffuser strongly depends on the loading coefficient as well as the opening angle. Abe[9] carried out experimental and numerical investigations for flow fields of a small wind turbine with a flanged diffuser. The results show that the power coefficient of the diffuser shrouded wind turbine was about four times as high as that of the bare wind turbine, and the power augmentation of this kind of wind turbine was mainly caused by the acceleration of the approaching wind by a flanged diffuser. Matsushima [10] studied experimentally and numerically the effects of a frustum-shaped diffuser on the output power of small wind turbine. Their results showed that the used diffuser parameters were able to increase the maximum wind speed at diffuser entrance by around 1.7 times and maximum energy production ratio of around 2.4 times was obtained by collecting wind energy in the turbine. Ohya [11] found hollow-structure diffuser is as effective as the shroud form wind turbine for collecting and accelerating the wind. Also they found when using a flange of proper height attached to the outer periphery of the diffuser exit, a remarkable increase in wind speed of 1.6－2.4 times that of the approaching wind speed power augmentation for a given turbine diameter and wind speed by a factor of about 4－5 compared to a bare wind turbine due to a low-pressure region in the exit area of the diffuser by vortex formation and draws the wind into the diffuser. Wang[12] used a scoop to improve energy capture from wind turbine at low wind speed. Their study used physical tests conducted in a boundary layer wind tunnel and commercial CFD code to get an optimal design of a scoop. The final design of scoop boosted the air flow speed by a factor of 1.5 times equivalent to an increase in power output of 2.2 times with the same swept area.

III. METHODOLOGY

In this section, basic steps in designing and simulation process of INVELOX are described with the effect of guide vane height at intake and throat diameter in model.

3.1. Design of Invelox Wind Turbine-

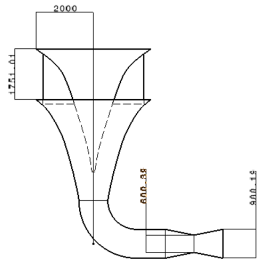
Solid model of INVELOX is designed in Catia according to size and dimensions of INVELOX model, and its geometry is imported to ANSYS for fluent analysis.

3.2 Design parameters

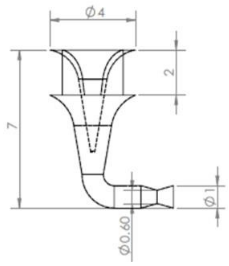
Here imvelox is modeled with 4 different guide vane heights as 1.75 m, 2 m, 2.25m, 2.5m and throat diameters as 0.6m.

Table -1 design parameter values

Parameter	**Dimension (m)**
Intake diameter	**4**
Guide vane height	**a) 1.75, b) 2, c) 2.25, d) 2.5**
Wind channeling height	**5**
Venturi inlet and outlet diameter	**1**
throat diameter	**0.6**



(a)



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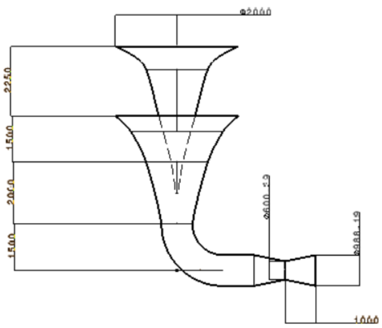

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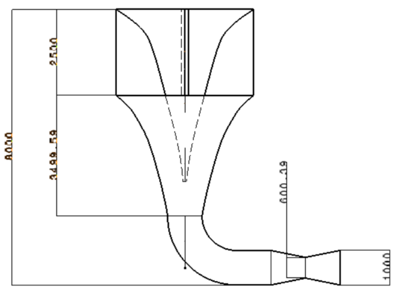
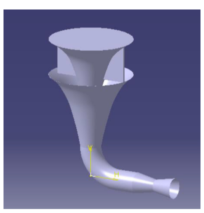


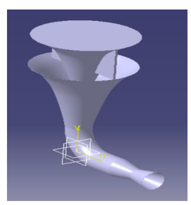
(d)

Figure 2. Geometry of invelox ducts with 4 different guide vane heights

3.3 Modelling-



(a)



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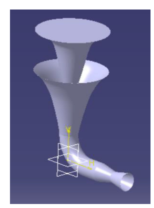

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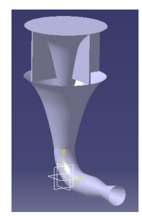


(d)

Figure 3. Solid modeling of invelox with differnt guide vane heights

The created geometry in catia software was imported into ansys design modeller to generate the computational models for cfd analsys. Here it is developed right rectangular prism around the 3D model which to make approximate boundary condition. It is extruded in such a manner to create an envelope around 3D model and then generate it. It is created Boolean to separate entities (rectangle prism and 3D object) and subtract 3D object from the right rectangular prism to develop cavity for the object under analysis.

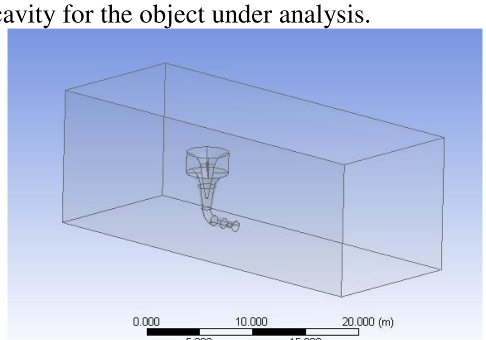


Figure 4. Computational fluid domine aroung the invelox

3.4 Mesh Generation-

Mesh generation is one of the most critical aspects of engineering simulation. Too many cells may result in longer solver runs, and too few may lead to inaccurate results.Thus, a compromise between the grid size on one hand and convergence and accuracy on the other hand is required. Hence, a grid independence study was carried out to ensure that the numerical solutions are grid-independent.

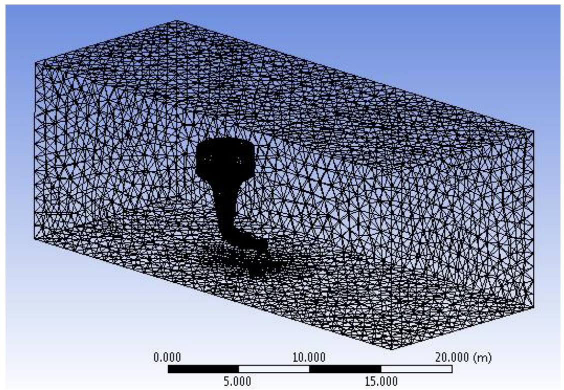


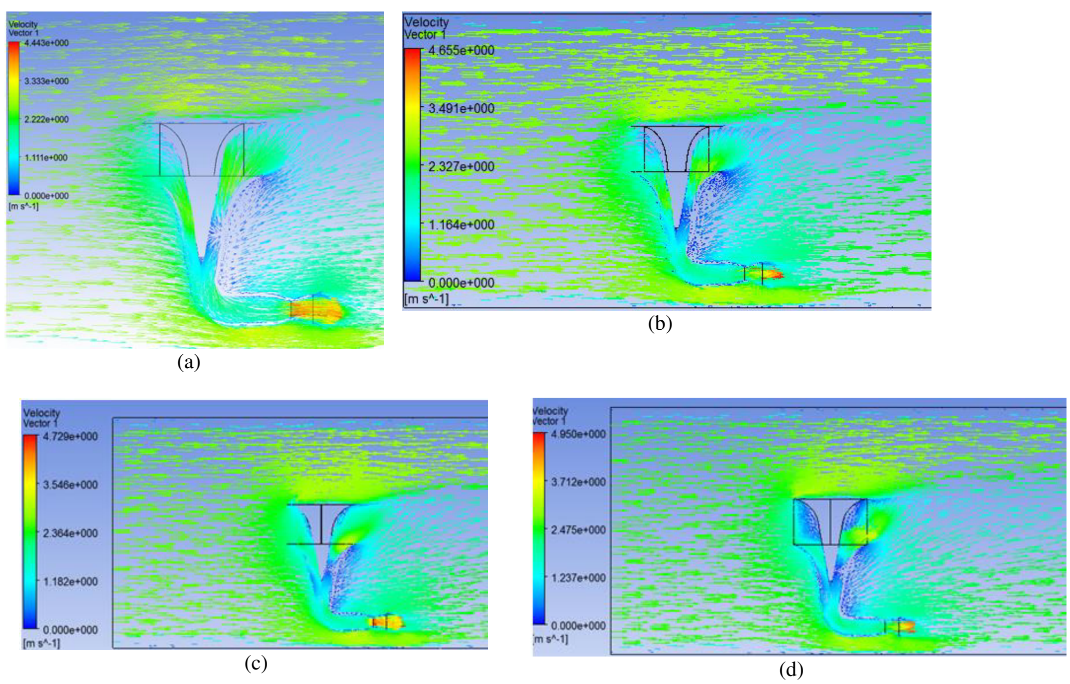
Figure 5. Meshed model of invelox duct

3.5 Boundary conditions-
inlet type - velocity inlet, Velocity magnitude - 2.66 m/s, outlet type - pressure outlet, Pressure gauge - 0.

IV RESULTS AND DISCUSSIONS

4.1 Velocity and Pressure Distribution of Wind through the Invelox Duct-

The cfd contours of velocity and pressure distribution of invelox duct with four guide vane heights a) 1.75 m, b) 2 m, c) 2.25, d) 2.5 m configuration shown below



(a) (b) (c) (d)

Figure 6. Velocity vectors of invelox duct with guide vane heights of a) 1.75 m, b) 2 m, c) 2.25 m, d) 2.5 m

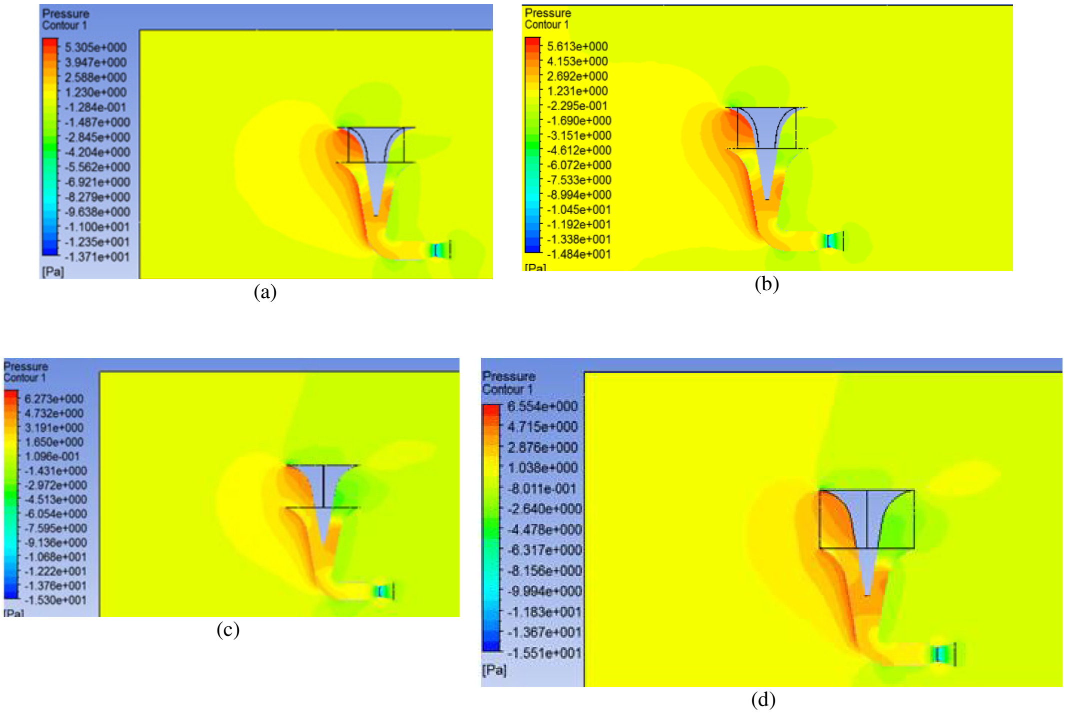


Figure 7. pressure contours of invelox duct with guide vane heights of a) 1.75 m, b) 2 m, c)2.25m, d) 2.5 m

It is observed that there is a significant decrease in the pressure of the wind from inlet to venturi exit of invelox system.

Table -2 Results of velocity with different guide vane height

Guide vane height (m)	Throat velocity (m/s)	Pressure(Pa)
1.75	4.4	6.921
2	4.67	7.533
2.25	4.72	8.415
2.5	4.9	8.945

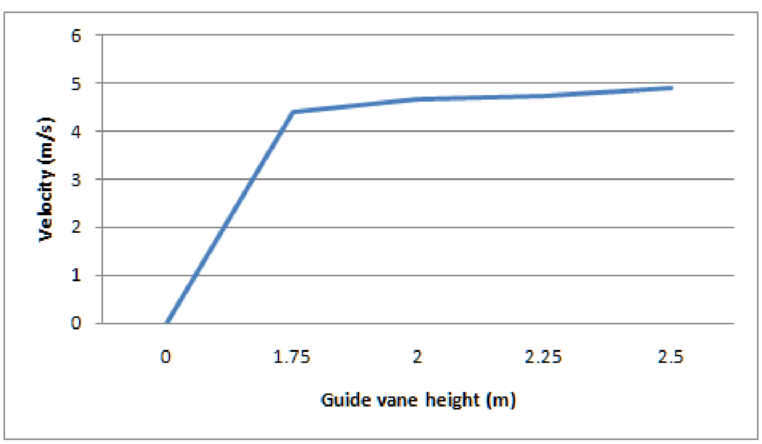


Figure 8. Variation of velocity with guide vane height

The velocity inceased from zero to nearly 5m/s with guide vane height of 0-2.5 m this is due to fluid flow principle of kinitic energy and height is related to potential energy, therfore velocity increses with height.

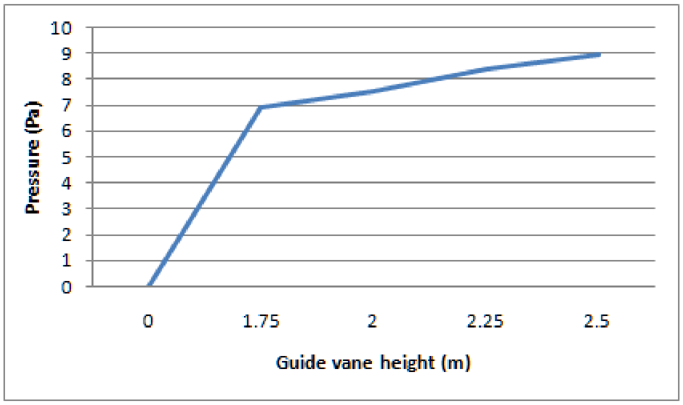


Figure 9. Variation of static pressure with guide vane height

4.2 Wind Power calculation:

P = ½ ρA [V] 3

Where, P = power of the wind [W], A = windswept area of the rotor (blades) [m2] = π/4D2, ρ = density of the air [1.225 kg/m3] (at sea level 15°C and 1atm), V = velocity of the wind [m/s].

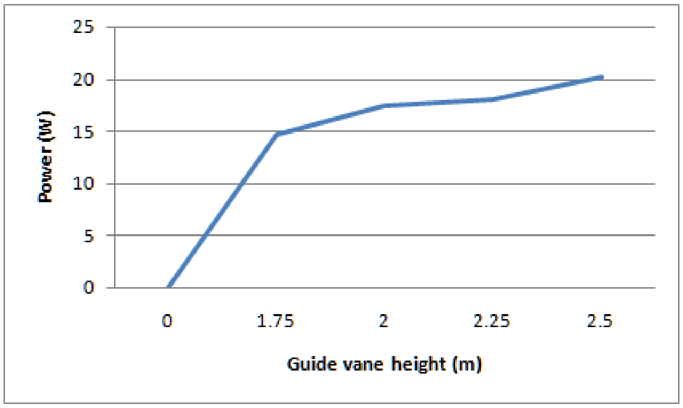


Figure 10. Variation of power produced by turbine with guide vane height

Table -3 Power of turbine with different guide vane height

Guide vane height (m)	Throat diameter (m)	Throat velocity (m/s)	Pressure (pa)	Power (W)
1.75	0.6	4.4	6.921	14.7
2	0.6	4.67	7.533	17.5
2.25	0.6	4.72	8.415	18.11
2.5	0.6	4.9	8.945	20.27
2	0.5	4.27	6.443	13.41
2	0.6	4.65	7.533	17.32
2	0.7	4.26	7.081	13.32
2	0.8	4.18	5.161	12.5

It is observed that with a same input velocity and guide vane height of invelox duct guide vane height is varying from 1.75 m to 2.5m the throat velocities are increased from 4.4 m/s to 4.18 m/s. It is observed that with the presence of invelox intake duct the velocity at exit of venturi section i.e. at inlet to wind turbine is getting increased with an average increase of 60%. With the use of invelox intake duct the theoretically maximum possible power for inlet velocity of 2.6 m/s and guide vane height varying from 1.75 m to 2.5 m/s is 14.7 W to 20.27 W and reduced to

12.5 as throat diameter is increasing. It is observed that with the use of invelox intake duct the theoretically maximum possible power for the case of Vin 2.6 m/s is 20.6% more compared to the case of without using the duct. On an average with the use of invelox duct the theoretically maximum possible power is more than 2.5times than that we obtain from conventional wind turbine under similar conditions.

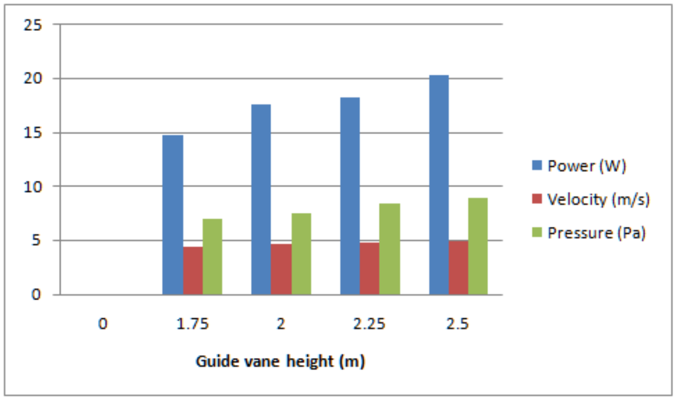


Figure 11. Comparision of parameters with guide vane height

from above figure it is observed that power prudced by sheer wind turbine is incresed with height as power is directly prepotional to twice the velocity that is very small fraction of change in velocity effect the output power. This power is developed at low velocity of less than 2m/s which is cut-in velocity for conventional horizontal wind turbine. It is also observed that by the increase of guide vane heights the wind power increases due to mass flow rate of air increased at inlet, and also the required power is obtained by adjusting the intake of invelox system, and here we proved that by cfd results. invelox system increase the wind speed from 2.6 m/s to 4.6 m/s at place of turbine and this leads to incrreses the power.

V.CONCLUSION

It is concluded that power obtained through sheer wind systems is 5-6 times more than that power obtained by conventional wind turbine of same velocity, less swept area and diameter without effecting the bird species and environment like sound pollution. Power has been increased about 38% with increased vane height of 2.5m with fixed throat diameter of 0.6m. Output of turbine is decreased by 28.5% with throat diameter increasing. Over all it is concluded that power and efficiency is increased for increased height at fixed throat diameter for sheer wind systems.

REFERENCES

[1] Daryoush Allaei, Yiannis Andreopoulos. "INVELOX: Description of a new Concept in wind power and its performance evaluation" Elsevier, Energy 69(2014) 336-344.

[2] Daryoush Allaei, David Tarnowski, Yiannis Andreopoulos. "INVELOX with multiplewind turbine generator systems" Elsevier, Energy 93 (2015) 10301040.

[3] G.M. Lilley, W.J. Rainbird, A preliminary report on the design and performance of ducted windmills, Report 102, April 1956, College of Aeronautics, Cranfield, England. (Alsoavailable as Technical Report CIT ll9, 1957, Electrical Research Assoc., Leatherhead,England).

[4] Ozer Igra, Compact shrouds for wind turbines, Energy Convers. 16 (4) (1977) 149−157.

[5] Ozer Igra, The shrouded aerogenerator, Energy 2 (4) (1977) 429− 439.

[6] Foreman, B. Gilbert, R.A. Oman, Diffuser augmentation of wind turbines, Sol. Energy20 (1978).

[7] B.l. Gilbert et al, Fluid dynamics of diffuser-augmented wind turbines, J. Energy 2 (6)(1978) 368−374.

[8] Ozer Igra, Research and development for shrouded wind turbines, Energy Convers.Manage. 21 (1981) 13−48.

[9] D.G. Phillips, P.J. Richards, G.D. Mallinson, R.G.J. Flay, Aerodynamic analysis andmonitoring of the Vortec 7 diffuseraugmented wind turbine, in: IPENZ Conference, 1998.

[10] M.O.L. Hansen, N.N. Sorensen, R.G.J. Flay, Effect of placing a diffuser around a windturbine, J. Fluid Mech. 3 (2000) 207−213.

[11] K. Abe, Y. Ohya, An investigation of flow fields around flanged diffusers using CFD, J.Wind Eng. Ind. Aerodyn. 92 (2004) 315− 330.

[12] K. Abe, M. Nishida, M.A. Sakurai, Y. Ohya, H. Kihara, E. Wada, K. Sato,Experimental and numerical investigations of flow fields behind a small-type wind turbine with flanged diffuser, J. Wind Eng. Ind. Aerodyn. 93 (2005) 951−970. B. Corona, M. Nakano, H. Pérez, "Adaptive Watermarking Algorithm for Binary Image Watermarks", *Lecture Notes in Computer Science, Springer, pp. 207-215, 2004.*