Numerical Simulation of Flow through Invelox Wind Turbine System

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Abstract- INVELOX is a recently developed wind capturing system suitable for wind power harnessing. Rather than grabbing bits of energy from the wind as it passes through the blades of a wind turbine rotor, the INVELOX innovation catches wind with a funnel and directs it through a tapering passageway that actually accelerate its move through a venturi section. INVELOX catches wind flow through an omnidirectional intake and subsequently there is no requirement for yaw control to orient the wind turbine.In the present work an attempt has been made to numerically simulate analyze the performance of an Invelox with a turbine. Initially the flow through a simple Inveloxwas simulated and the results validated with the developer's results. The developed Invelox model was then analyzed with inclusion of a wind turbine to achieve a wind speed of 11.90 m/s at venturi section giving a speed ratio of 1.72. Comparison between Invelox wind turbine system and a traditional wind turbine was also attempted under similar conditions. Results indicate that the Invelox system can generate about 6 to 8 times more energy than the traditional wind turbine with the same size of turbine. The performance of Invelox system was analyzed with wind flows from 8 different directions (0˚, 45˚, 90˚, 135˚, 180˚, 225˚, 270˚, 315˚, 360˚) with respect to turbine axis. It is observed that higher speed ratios are achieved in all case expect 135˚ and 225˚ angles. Highest wind speed ratio of 2.014 is achieved in case of 45˚ and 315˚ angles.

Keywords: Wind energy, Wind turbines, Performance Analysis, Comparison, Power.

1. Introduction

1.1 Introduction of INVELOX

In order to make wind power an acceptable mainstream in electrical energy generation industry, anadvance approach, with disruptive features, needs to be developed. Such a disruptive approach and way of thinking, with no doubt initially and naturally, will generate huge resistance and opposition from current experts in the industry. A recently developed technology, Invelox (increased velocity), has shown good results. Invelox is simply a wind capturing and delivery system.

While traditional wind turbines utilize monstrous size of turbine and generator systems mounted on top of a tower. In Invelox, wind contrast in funnels and wind energy transfer to ground-based generators. Instead of snatching bits of energy from the wind as it passes through the blades of a rotor, the Invelox technology captures wind with a funnel and directs it through a tapering passageway that passively and naturally accelerates its flow. This stream of kinetic energy then drives a generator that is installed safely at ground or sub-ground level.[11]

The concept of capturing and accelerating wind is based onprinciple of old ducted turbine combining both Bernoulli and venturi principle. Invelox is a unique innovation that the wind industry desperately needs. A reason to be doubtful of Invelox is that, in the past ducted turbines have not made any significant headway in the industry due to financial viability, even though positive performance was in general validated. It is also sensible to question whether, once a turbine is placed inside an Invelox system, the increase in speed might no longer be maintained, making the promise of superior performance no longer valid.

It should be noted, however, that the same is true for traditional open-flow systems. The free stream wind reduces speed when approaching the blades; it could reduce to a half to two-thirds, depending on the environmental and blade profile factors. In the case of turbines inside Invelox also, the increased wind speed reduces when approaching the blades. The level of decrease is same range as with open flow, however as the approach speed is high the aped after reduction will also be relatively higher. Invelox technology has the potential to provide affordable electrical energy from micro to mega scale.

1.2 Working Principle of Invelox Wind Turbine System

The name INVELOX comes from increasing the velocity of wind. The technologywas introduced by Dr. DaryoushAllaei. Invelox captures, accelerates and concentrates the wind thus increasing the wind power.

In Invelox, wind flow converges through funnel and increase the wind speed, this converts to electric power by using turbine-generators system. Wind is captured with a funnel and directed through a tapering passageway that naturally accelerates its flow. This stream of kinetic energy then drives a generator that is installed safely at ground level.

Bringing the airflow from top of the tower to ground level increases the kinetic energy and thus allows for greater power generation with much smaller turbine blades. It also allows for networking using multiple towers to direct energy to the same generator.

2. Descriptionof the INVELOX Delivery System

The five key parts of Inveloxare 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) Diffuser.

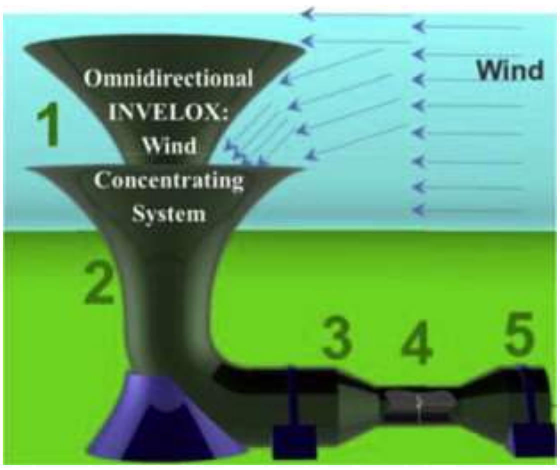

Fig.1 Schematic of the INVELOX wind delivery system with its key components[3]

At a first glance, Invelox appears to be another ducted turbine. In fact the ducted turbine has been traced to the work conducted in Finland in 1930s. The subject of ducted turbines has resurfaced in every decade since 1930s. However without exception, in all the ducted turbines that have been tried to date, the turbine location and the intake are strongly coupled. In other words, if one wishes to scale up the system to utility scale, not only does the blade increases in size but also the duct structure increases in size and impacts the cost substantially. There are various examples of failed ducted turbine products because they were not financially viable. At the same time there are no other savings to compensate for the huge cost of the additional structures that is needed to align the structure with the wind direction. Hence 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. In contrast to older designs of ducted turbines, Invelox separates the location of the shroud and turbine-generator system. The intake is on the top of the tower, while the turbine-generator is placed at the ground level inside the ducted pipe carrying captured wind towards the turbine. This unique feature allows the engineers to size the intake wind delivery system for any required speed increase without increasing the turbine size. The size of an intake depends on local wind speeds and other environmental conditions like Land Use, Wildlife and Habitat, Public Health and Community. Alternately, the turbine size may be selected based on the ability of the Invelox to increase wind speed/mass flow rate. The turbine-generator system is installed at ground level and inside the diverging location of the horizontal section of Invelox, resulting in significant cost savings at the time of installation as well as during operation and maintenance for the life of the system. Because there is no moving component on the top of the tower, most adverse environmental impacts are eliminated or minimized.

INVELOX allows a much lower cut-in speed because it can increase wind speed at the location of the turbine. For example, if Invelox is designed to increase free stream wind speed by a factor of 4 at the turbine location, and it uses a traditional turbine that has a cut-in speed of 4 m/s, the cut-in speed of the Invelox turbine system will be 1 m/s. Having a reduced cut-in speed is one of the most important features offered by Invelox. This feature not only allows an increase in annual energy production and capacity factor but also increases wind power availability. It allows installation of Invelox in wind class 1 and 2 areas. It also allows Invelox to be installed much nearer to the end user, thereby significantly reducing transmission losses and added costs. Invelox does not require the huge upfront capital cost of traditional wind technology nor does it leave a negative environmental impact.

ThusInvelox has the potential to reduce the net cost of utility scale wind power generation by reducing installation, Operation & Maintenance, turbine and land costs while improving energy production and environmental impacts.[3]

2.1 Key features of INVELOX[3]

The key features of Inveloxcan be summarized as follows:

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 decoupling of intake and turbine location allows the WTG (Wind Turbine Generator) be mounted at the ground level and thereby reduces Operation & Maintenance cost.
3) Decoupling of the intake and venturi, where the turbine is installed, allows designing Invelox with a speed ratio of 6 or higher. This facilitates operating the wind turbine at high wind speeds and thus generating a lot more power can be scaled with smaller blades with high speed efficient generators.
4) Due to operation at higher wind speeds, the blade size can be reduced up to 85%, which results in cost savings in material, manufacturing, transportation and installation.
5) The intake is designed to be omnidirectional and thus there is no need for huge bearing and motors to turn the intake in the direction of wind.
6) Inveloxcan be designed for a wide range of power rating 500 W to 25 MW. Depending upon, how much air is captured.
7) The decoupling of the intake and turbine allows multiple intake be connected to increase mass flow and thus power output.

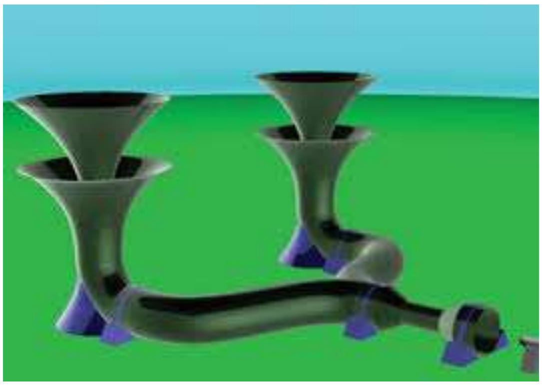

Fig.2 Multiple intake system

3. NumericalSimulation

For the numerical simulation, modeling of the geometry was done using ICEM CFD software. The basic geometric models created for numerical simulations are as follows:

1) Simple Invelox
2) Traditional Wind Turbine
3) Invelox with Wind Turbine

3.1 Simple Invelox Model

In the present work, the dimensions of Inveloxwere taken to be same as that used by the developers. The model consists of a double nested cone with 360° wind intake capability. The top cone is the guide directing wind into the lower cone. The top cone has a diameter of 12.192 m and height of 12.203 m. The lower cone has 2 different size of diameter at the top and bottom, which are 12.192 m and 3.048 m respectively.

Distance between two cones is 6.096 m. The pipe bend has same diameter of 3.048 m and its bend at 4.572 m radius. The throat of venturi section has 1.829 m diameter. The converging and diverging pipe length is 3.048 m each. The total height of the Invelox tower is measured from the center of intake to the ground level, which is 18.288 m. The inlet contains four partitions symmetrically positioned at 90°, 180°, 270° and 360° about the vertical axis of the axisymmetric intake.

As the 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. According to the dimensions, the geometry is designed in ICEM CFD software. Fig. 3 & 4 shows respectively the detail dimensions and geometry of omnidirectional Invelox modeled.

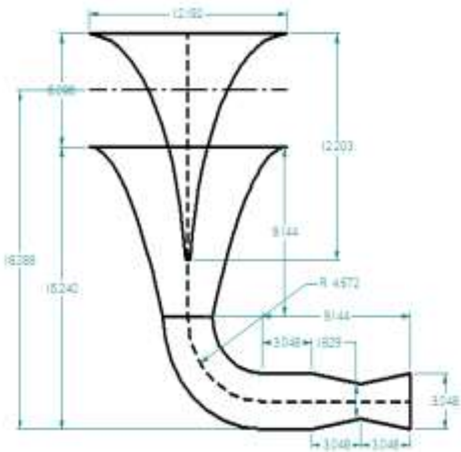

Fig.3 Dimension (in m) of INVELOX

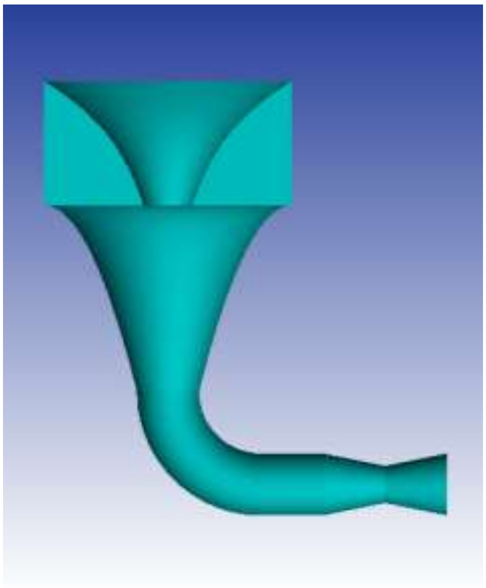

Fig.4 Geometry of INVELOX

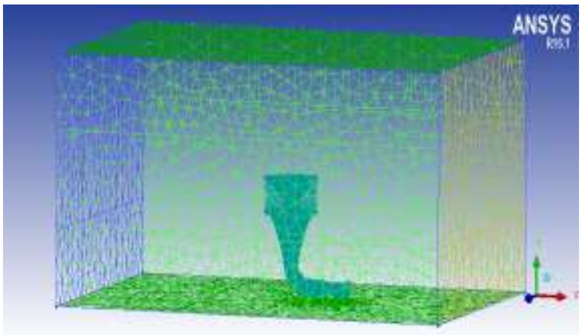

Fig.5CFD model showing INVELOX and Domain

Fig.5 shows Invelox surrounded by a domain size of 60.96 m (200 ft) × 91.44 m (300 ft) × 45.72 m (150 ft). The domain consists of 6 sides from which, left side is named as Inlet, and right side is named Outlet. And other 4 sides top, bottom (considered as ground), front and back named as Wall. The Invelox was placed in a center of domain such a way that, it's just above the bottom plane and at equal distant from Inlet and outlet.

3.2 Traditional Wind Turbine Model

The performance analysis of a traditional wind turbine has been done to compare the results with that of a turbine placed in an Invelox. Hence the turbine size was selected such a way that, it can be placed in the venturi section of the Invelox. This in the present case has a radius of 0.9144 m. Hence for this analysis, the geometry of a wind turbine of radius 0.8668 m has been adopted from the report prepared by J. L. Tangier and D. M. Somers, National Renewable Energy Laboratory, Colorado.

Adopted wind turbine has following dimensions and features:
Rotor Radius: 0.8668 m
Hub Radius: 0.0476 m
Airfoil: NERL S801, S803 and S804
Number of Blades: 3

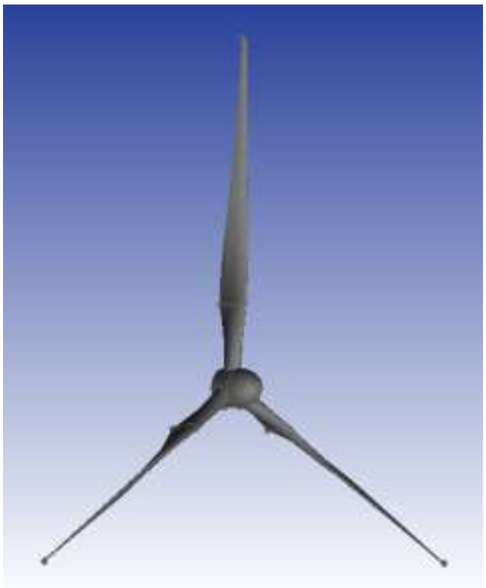

Fig.6 Designed Wind Turbine

To analyze the wind turbine performance in normal atmosphere with free stream wind, it is mounted on tower and placed in the center of the domain, which had a size of 30.48 m (100 ft) × 45.72 m (150 ft) × 22.86 m (75 ft). The domain consists of 6 sides from which, left side is named as Inlet, and right side is named Outlet. And other 4 sides top, bottom (considered as ground), front and back named as Wall.

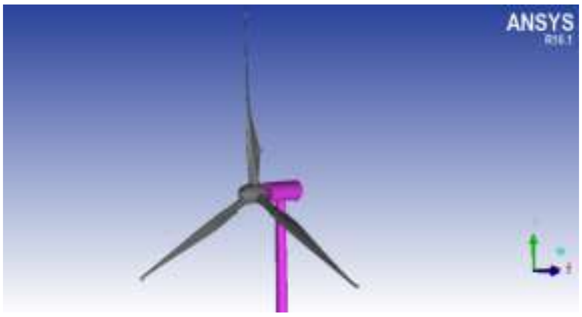

Fig.7 Wind Turbine Geometry with Tower support

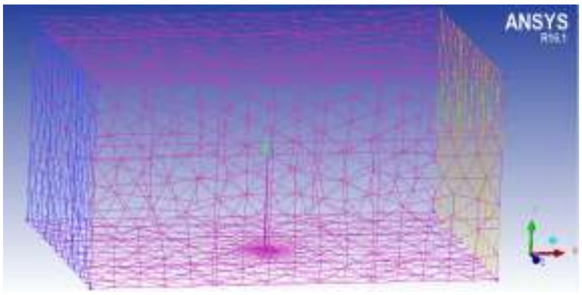

Fig.8 Meshing of Wind Turbine and Tower support

3.3 Invelox system with Wind Turbine

In the Invelox system, the wind turbine is to be placed in the venturi section axisymmetrically. In the present case the geometry of the same wind turbine as used in the stand alone model has been used for wind turbine placed inside the Invelox. First the geometry of wind turbine was modeled independently. Using the axis coordinate system as for Invelox and then it is imported in the Invelox geometry in such a way that it gets placed in the venturi section axisymmetrically, as shown in the fig.9.

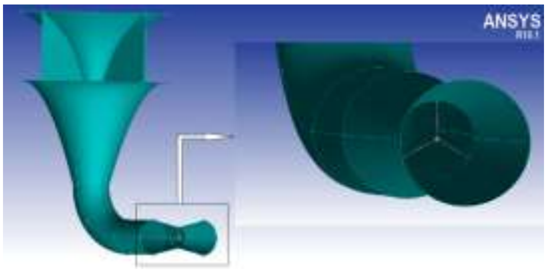

Fig.9Invelox system with Wind Turbine

Since the performance was to be analyzed for different wind directions, 5 variants of the basic geometry were modeled with Invelox rotated at different angles with respect to the inlet of the domain. The models of variants are shown in below figures.

Case 1: Invelox placed on ground at 0˚ to wind direction.

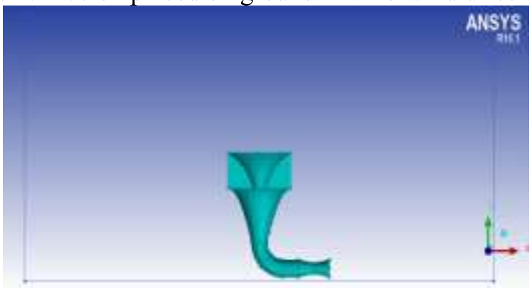

Fig.10 Invelox at 0˚

Case 2: Invelox placed on ground at 45˚ to wind direction.

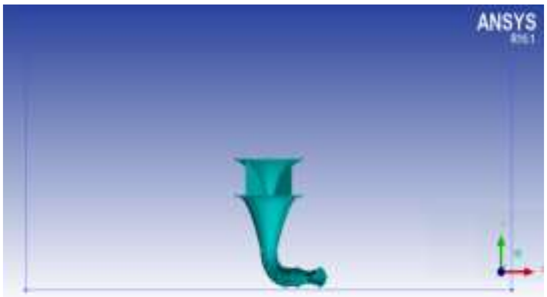

Fig.11 Invelox at 45˚

Case 3: Invelox placed on ground at 90˚ to wind direction.

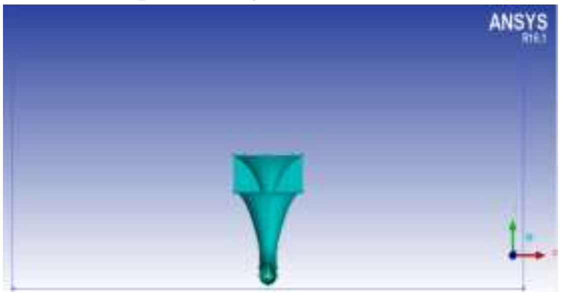

Fig.12 Invelox at 90˚

Case 4: Invelox placed on ground at 135˚ to wind direction.

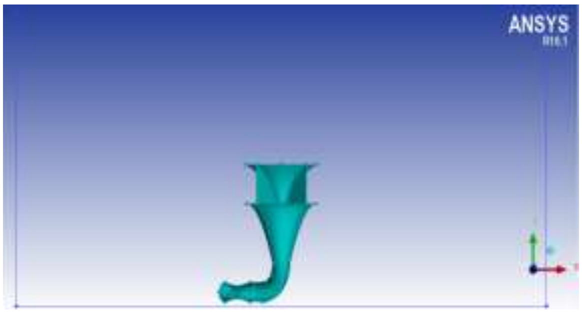

Fig.13 Invelox at 135˚

Case 5: Invelox placed on ground at 180˚ to wind direction.

Fig. 14 Invelox at 180˚

3.4 Meshing

The flow domain was discretized with a different size of mesh on each part for the better accuracy. On the domain maximum size of element is 4, on Invelox 0.5, on wind turbine 0.003 and on the support 0.02; which shows that extra fine mesh used on the wind turbine pats and system. So for the simulation minimum 436066 nodes, 2196711 elements and maximum 437947 nodes, 2207409 elements are used.

3.5 Pre-Processing

Preprocessing of the modeled geometries was done to define the domain and boundary conditions. A constant input velocity field, representing the free stream wind, was assigned to the entire frontal plane of the flow domain. For the inlet, source air with 5% turbulence intensity was used, while a length scale of turbulence 1.0 m was used in the ANSYS computations. Second-order accuracy upwind schemes and standard k–epsilon turbulence model closures with standard wall functions were specified for solution of equation. Initially, in order to compare the results with those of the developer's, the magnitude of the velocity was kept as 6.7 m/s (15 mph). The reference pressure was assumed to be the atmospheric pressure throughout the domain.

3.6 Domain Basic Settings

In all cases fluid material is taken as air at 25˚ C, which is considered as continuous fluid. The whole analysis carried out by considering all parts as stationery. Reference pressure was set to be the 1atm. For the analysis, k–epsilon turbulence model has been used in all cases.

3.7 Boundary Conditions

The Inlet and Outlet parts of the model geometry are define as the inlet and outlet boundary in the boundary conditions. For the considered domain, free wind speed at inlet is given as 6.7 m/s with 5% of turbulence and at outlet relative static pressure is set to 1 atm. For the performance analysis of Invelox with wind turbine and traditional wind turbine, 28 simulations were performed with wind velocity varying from 0.5 m/s to 14 m/s at intervals of 0.5 m/s. Remaining surrounding walls of the domain are considered as smooth wall with no slip condition. The boundary conditions for Invelox and wind turbine were also set as wall with no slip condition.The open wind turbine and Invelox with wind turbine have some additional boundary conditions, where the wind turbine and support tower were specified as no slip wall.

The Residual target was set as $1\,e^{-6}$, with maximum 500 iteration. The simulation results are discussed in next section.

4. Result and Discussion

In the present work initially numerical simulation was performed for simple Invelox and the obtained results were validated with those of the developers. Thereafter simulations were performed to compare the performance of Traditional wind turbine and Invelox with wind turbine at different wind speeds, which shows that the Invelox wind turbine give a batter performance. Thereafter simulations were performed to analyze the performance of Invelox with wind turbine system under different wind directions. The performance comparison of Traditional wind turbine and Invelox wind turbine system has also been carried out on the bases of potential to generate power in both systems.

4.1 Simulation Results for Invelox (without wind turbine)

Simulation for the basic model was performed for validation, where the Invelox inlet is parallel to wind direction. The results were compared with those of the developer's result. The comparison is based on the velocity distributions and speed ratio in the absence of the turbine.

The developers had used COMSOL Software, for numerical analysis in the present work analysis has been carried out using ANSYS software. The performance output of the present system depends strongly on the accelerated wind velocity at venturi section of the intake. Hence velocity has been used as the parameter for comparison of results. The velocity profiles obtained on the symmetry plane of the Inveloxtower given by the inventor of Invelox and the simulation results of the present study are shown in Fig. 15 and 16 respectively. The profiles in both cases are similar in nature. The magnitude of average wind speeds inside the venturiare also comparable in both the cases, as shown in Tables 1.

Table.1 Result Comparison

Unit m/s	Free Stream Wind Speed	Average Velocity at Venturi Section
Developer's Result	6.7056	12.2042
Present Simulated Result	6.7	12.3751
Difference	-0.08%	1.4%

The results generated from the present model are in agreement with those of the developer's. Hence the numerical model can be used for further numerical analysis

Analysis of Flow through Simpler Invelox

Analysis of flow pattern as seen in figures 15 and 16 show that the captured air flow is diverted by the intake downwards into the piping system of the tower and after taking a 90° turn reaches the venturi section where it is accelerated as shown in both simulations. The velocity distribution as seen in the velocity contours appear to be similar. Both the case indicates that the velocity increases from the inlet section, as the flow moves towards pipe section and it becomes maximum at venturi section. Thereafter it again decreases while moving towards the diffuser. Maximum velocity achieved in both the cases is about 12.2 m/s.

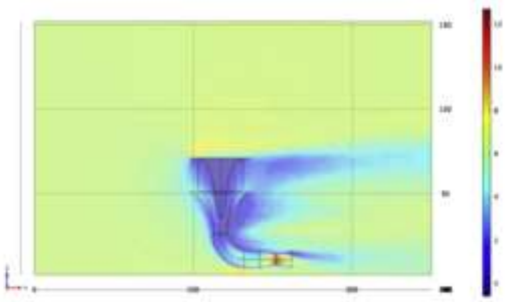

Fig.15 Developer's Result, obtained in COMSOL Software[3]

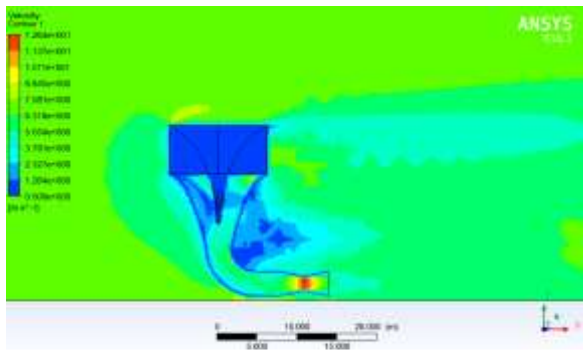

Fig.16 Present simulated Result obtained in ANSYS

The intake captures the free stream flow in a complex way. As can be seen in the velocity vector plot in top view (Fig.17) major part of the incoming flow hits on the fins wall of the front quadrant of the intake formed by the four partitioning baffles and is diverted downwards inside the delivery system. While some part of the incoming free stream wind is deflected to the sides of the intake and it separates at the tip of the two fins.

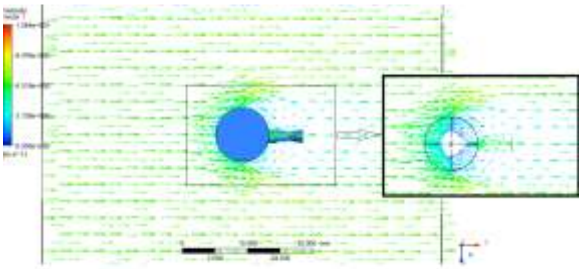

Fig.17 Velocity vectors predicted by ANSYS on a horizontal plane perpendicular to the axis of symmetry of the intake.

Velocity vector plot in vertical plane (Fig.18-19) shows that while most of the vectors point towards downward direction, some of the wind moves back upwards from below the innercone due to the low back pressure on the other side of the inner cone.

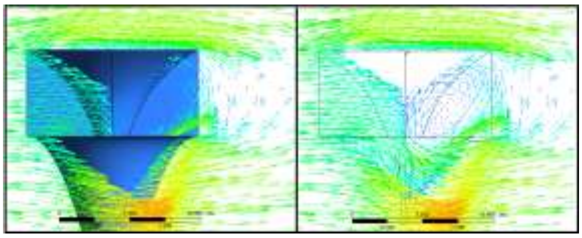

Fig.18 Velocity vectors on a Vertical plane

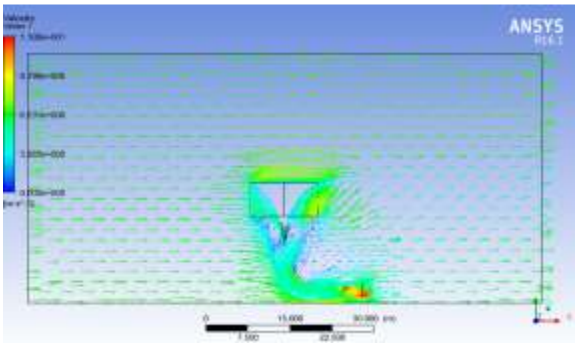

Fig.19 Velocity vectors on a Vertical plane perpendicular to the axis

The variation of pressure can be seen clearly in the pressure contour plot given in Fig.20. The vector plot shows that flow inside the funnels appears to be non-uniform and there is separation zone below the fins, surrounding the tip of inner cone. Overall, the intake captures a substantial amount of free stream flow despite the flow separation and same flow exiting the intake at the opposite side of inlet.

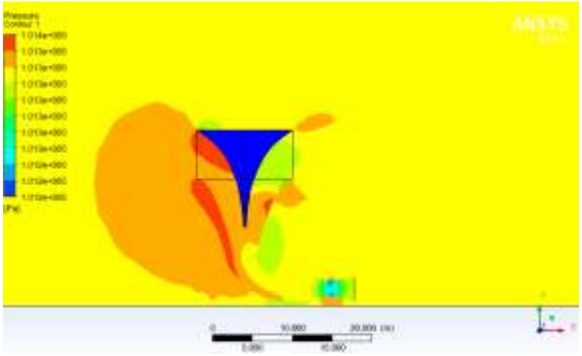

Fig.20 Pressure Contour

The average wind speed calculated at the mid of venturi section for a simple Invelox is about 12.20m/s when the free stream wind speed is 6.7 m/s. This results in an average speed ratio (SR) of about 1.82.

4.2 Simulation Results of Invelox with Wind Turbine

Initially, the Invelox system was analyzed without wind turbine for validation purpose. However Invelox has been developed with an aim to enhance the performance of wind turbine. Hence, further analysis is performed along the axis of wind turbine with a turbine inside the Invelox.The free stream wind speed is taken same as 6.7 m/s in the direction of velocity contour plot across the venturi section obtained for the simulation is given in Fig.21.

The obtained average wind speed at the venturi section is about 11.99 m/s; this results in an average speed ratio (SR) of about 1.78. The performance of the Invelox with turbine was further analyzed for different free stream wind speed. The wind speed was varied from 0.5 m/s to 14 m/s at increments of 0.5 m/s. The achieved wind speed obtained at the venturi section for the cases are given in table 2.

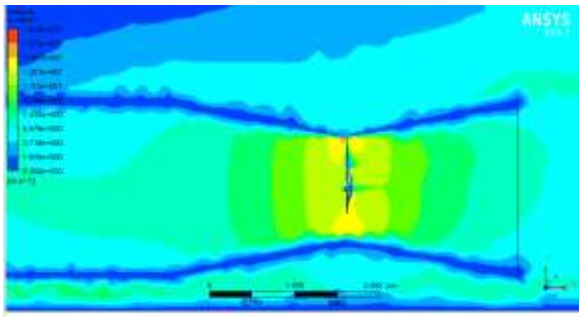

Fig.21 Velocity profile of venturi section with Wind Turbine

Table.2 Velocity achieved at different Wind speeds

Actual Wind Speed	**Avg. Speed Achieved at Venturi Section**
m/s	m/s
0.5	0.7720

1.0	1.7243
1.5	2.6044
2.0	3.4947
2.5	4.3804
3.0	5.2717
3.5	6.1736
4.0	7.0744
4.5	7.9749
5.0	8.8849
5.5	9.7983
6.0	10.7122
6.5	11.6278
6.7	11.9906
7.0	12.5452
7.5	13.4569
8.0	14.3755
8.5	15.2920
9.0	16.2127
9.5	17.1319
10.0	18.0532
10.5	18.9726
11.0	19.8960
11.5	20.8190
12.0	21.7438
12.5	22.6679
13.0	23.5917
13.5	24.5177
14.0	25.4440

4.3 Comparison of Invelox Wind Turbine and Traditional Wind Turbine

In order to make meaningful comparisons with traditional turbines, additional analysis were carried out by placing the same turbine used in the Invelox in atmosphere. Thus, the performance of this set up with the turbine placed on the top of a traditional tower in the domain could be directly compared with the Invelox data.

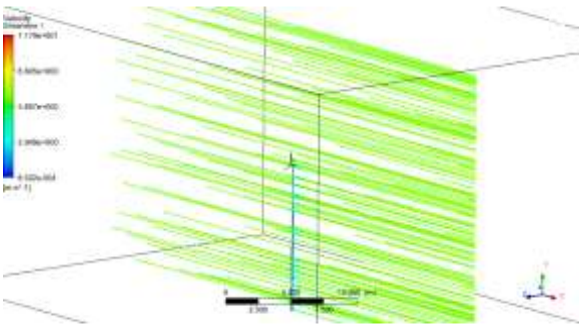

Fig.22 Streamlines pattern for traditional wind turbine

The velocity contours on the wind turbine obtained in both the cases are shown in the fig. 23 and 24. The maximum velocity along the blades is in the range of 11-12 m/s for Invelox wind turbine as compared to 5.5-7 m/s for traditional wind turbine. It is observed that comparative to traditional wind turbine, Invelox wind turbine gets much higher cut-in wind speed.

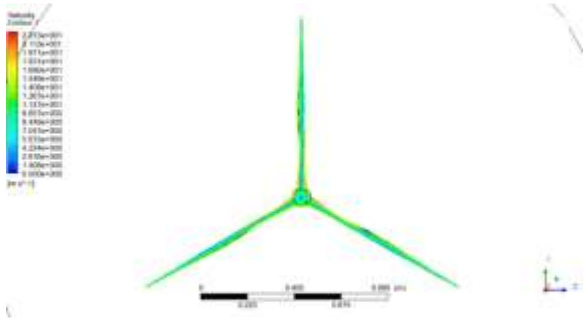

Fig.23 Invelox wind turbine Contour

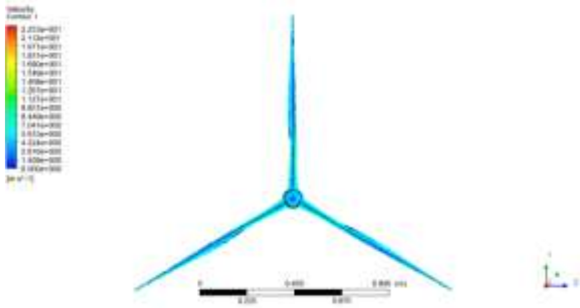

Fig.24 Traditional wind turbine Contour

For further analysis, both systems are analyzed for different free stream wind speed. The wind speed was varied from 1 m/s to 14 m/s at increment of 1 m/s. The cut-in wind speeds obtained in both the cases are tabulated in the table 3.

Table.3 Wind Speed Achieved by Wind Turbine

Actual Wind Speed	Avg. Vel.	
	INVELOX	TWT
m/s	m/s	
1.00	1.724	0.915
2.00	3.495	1.819
3.00	5.272	2.731
4.00	7.074	3.638
5.00	8.885	4.544
6.00	10.712	5.451
6.70	11.991	6.087
7.00	12.545	6.359
8.00	14.376	7.266
9.00	16.213	8.172
10.00	18.053	9.080
11.00	19.896	9.987
12.00	21.744	10.895
13.00	23.592	11.803

14.00	25.444	12.710

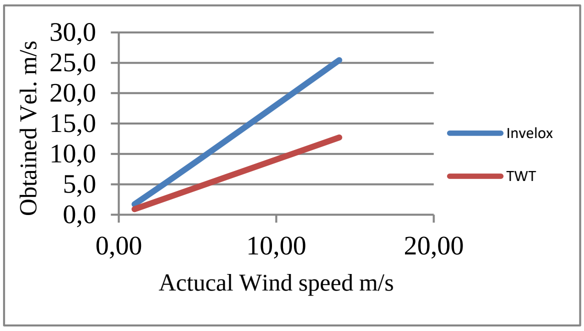

Fig.25 Avg. Velocity comparison of Invelox and Traditional Wind Turbine

Fig.25 shows that higher wind speeds were maintained even when a turbine was placed inside the venturi section of Invelox.

Comparison of power generation capacity of INVELOX and Traditional Wind Turbine were also made. For which the considered data are as follows:

Density$\boldsymbol{\rho}$ = 1.1839 kg/m^3 at 25 Deg
Radius $\boldsymbol{r}$ = 0.8668 m
Swept Area $\boldsymbol{A}$ = 2.3596 m^2
Power Co-eff. $\boldsymbol{C_p}$ = 0.4

$$P_{avail} = \frac{1}{2} \cdot \rho \cdot A \cdot v^3 \cdot C_p$$

Table.4 Predicted Power generation capacity for both systems

Actual Wind Speed	Avg. V		Power P	
	Invelox	TWT	Invelox	TWT
m/s	m/s		Watt	
1.00	1.724	0.915	2.976	0.444
2.00	3.495	1.819	24.775	3.496
3.00	5.272	2.731	85.043	11.821
4.00	7.074	3.638	205.517	27.939
5.00	8.885	4.544	407.138	54.448
6.00	10.712	5.451	713.545	94.007
6.70	11.991	6.087	1000.710	130.889
7.00	12.545	6.359	1146.089	149.240
8.00	14.376	7.266	1724.465	222.641
9.00	16.213	8.172	2473.725	316.839
10.00	18.053	9.080	3415.451	434.585
11.00	19.896	9.987	4571.753	578.222
12.00	21.744	10.895	5967.491	750.639
13.00	23.592	11.803	7621.898	954.447
14.00	25.444	12.710	9561.843	1191.823

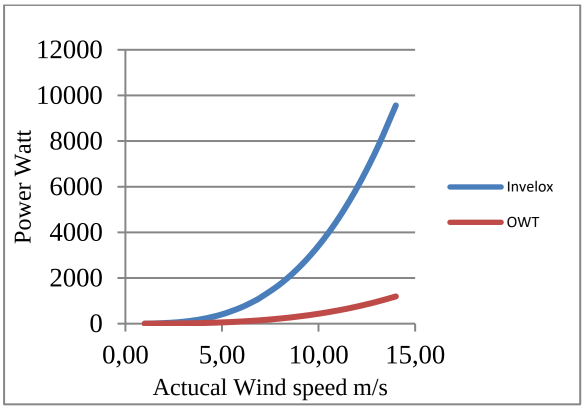

Fig.26 Predicted Power generated by each system

It is observed that in general, Invelox wind turbine system can generate about 6 to 8 times more power than the traditional wind turbine system. As results shows that at any free stream wind speed,Invelox gives best performance for power generation, hence further analysis was carried out for Invelox wind turbine system.

4.4 Invelox: Wind from Different Direction

Invelox is the system which can capture wind from any direction. In earlier cases, the free stream wind is flowing parallel to wind turbine axis practically wind can flow in any direction. Hence the Invelox wind turbine system has been analyzed for different wind direction with respect to wind turbine axis. For analysisInvelox position has been rotated at different angles, so that the free stream wind direction changes accordingly with respect to wind turbine axis. The analysis was performed for wind at 0˚, 45˚, 90˚, 135˚ and 180˚ with respect to turbine axis. The streamline patterns for these cases are shown in fig. 27 to 31.

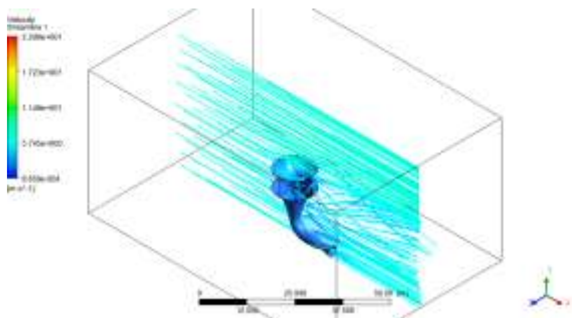

Fig.27 Invelox outlet at 0˚ to wind turbine

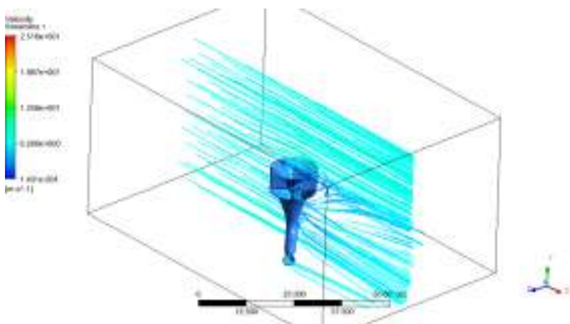

Fig.28 Invelox outlet at 45˚/315˚ to wind turbine

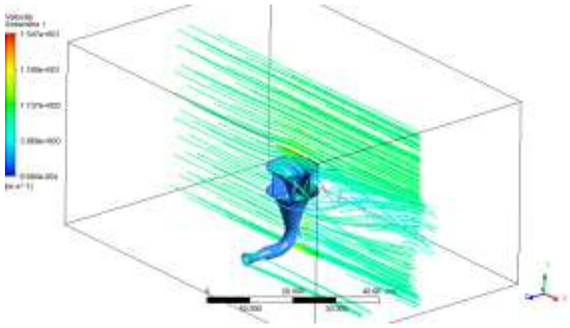

Fig.29 Invelox outlet at 90˚/270˚ to wind turbine

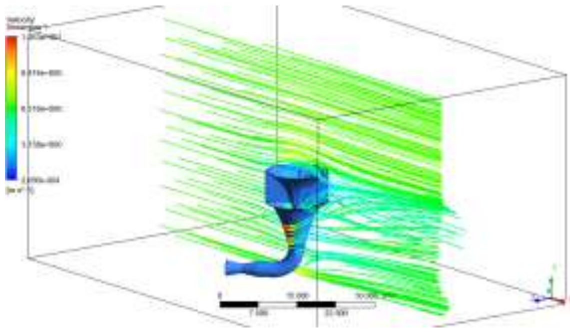

Fig.30 Invelox outlet at 135˚/225˚ to wind turbine

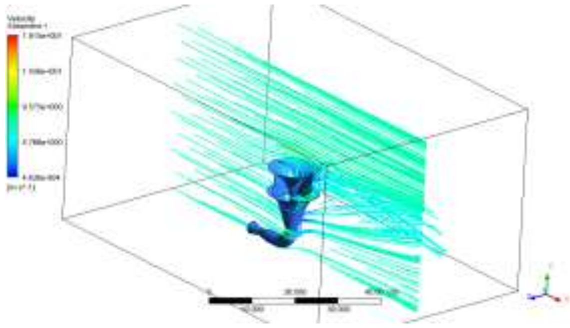

Fig.31 Invelox outlet at 180˚ to wind turbine

It is observed that, when the Invelox is placed at 45˚ angle to the wind direction, the losses on the side fins are lower as the wind goes directly to funnel. In other cases when wind strikes to perpendicular fins, some amount of wind escapes from the sides circumferentially and less amount of wind goes in to the funnel. Based on the analysis result, the wind speed achieved at the venturi section is tabulated in given table 5.

Table.5 Wind speed achieved at the venturi section

Angle	Actual Wind Speed	Speed Achieved
degree	m/s	m/s
0˚	6.7	11.9301
45˚	6.7	13.5094
90˚	6.7	8.10112
135˚	6.7	5.31639
180˚	6.7	8.92595
225˚	6.7	5.31639
270˚	6.7	8.10112
315˚	6.7	13.5094
360˚	6.7	11.9301

In general it is seen that the Invelox is omnidirectional as higher cut-in speeds are achieved at all angles except 135˚/225˚. Further it is observed that the best performance is achieved at an angle of 45˚/135˚, where the maximum velocity reaches 13.50 m/s and the obtained wind speed ratio is 2.014. So for the best performance result, the Invelox outlet position should be rotated at an angle of 45˚/315˚ with respect to wind direction. The pictorial representation of actual wind speed and achieved wind speed is shown in fig. 32.

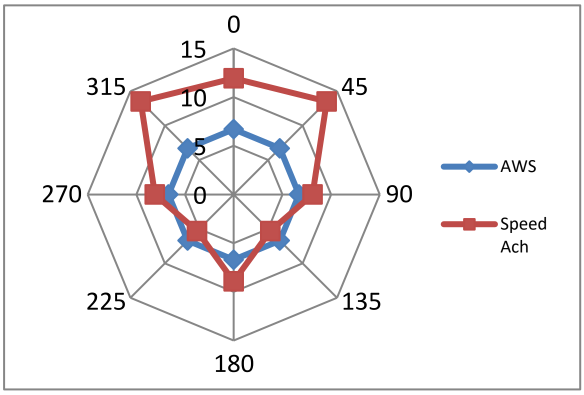

Fig.32 Actual wind speed against speed archived at different angle

5. Conclusions

In the present work numerical simulation and analysis of Invelox wind turbine system has been performed to determine its advantage in terms of power generation capacity over Traditional wind turbine system. Various conclusions drawn from the above simulation and analysis are mentioned below:

i. The simulation results of the basic Invelox model are in good agreement developer's results hence the model can be used for further analysis.
ii. TheInveloxsystem with wind turbine achieved 11.90 m/s wind speed at venturi section with 1.72 speed ratio.
iii. Comparison between Invelox wind turbine system and a traditional wind turbine has been attempted under similar conditions. Results indicate that the Invelox wind turbine system can generate about 6 to 8 times more energy than the traditional wind turbine systems with the same size of turbine.
iv. The performance of Invelox system was analyzed with wind flows from 8 different directions (0˚, 45˚, 90˚, 135˚, 180˚, 225˚, 270˚, 315˚, 360˚) with respect to turbine axis. It is observed that higher speed ratios are achieved in all case expect 135˚ and 225˚ angles. Highest wind speed ratio is achieved in case of 45˚ and 315˚ angles.
v. As Invelox system can generate power even at low wind speeds, it can be installed even in areas which

lie in wind class zones 1 and 2. ThusInvelox has a strong potential to generate much more energy than traditional wind turbines.

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