Using CFD to Predict the Performance of Innovative Wind Power Generators

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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 INVELOX. The model was developed using COMSOL package. 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.

Keywords: INVELOX, Wind, Venturi, Energy.

1. Introduction

The patented INVELOX product line [1-2, 3-4] is an innovative wind power generation system comprised of a wind capturing system that accelerates and delivers high kinetic energy wind to a power conversion system placed in its Venturi section. The fundamental innovation of the INVELOX system is that it eliminates the need for tower-mounted turbines while it capturers wind flow through an omnidirectional intake. It is claimed that INVELOX, standing for INcreases VELOcity, outperforms traditional wind turbines by delivering superior power output, at reduced cost, and in the process, solves all the major issues, such as low turbine reliability, intermittency issues and adverse environmental and radar impact, that have so far undermined the wind industry. One of the key measures to validate this claim is the degree of increased speed in the Venturi. The objective of this project is to build a full scale model to verify laboratory and field test data. The validated model is utilized as an effective design tool for future development.

2. Problem Definition

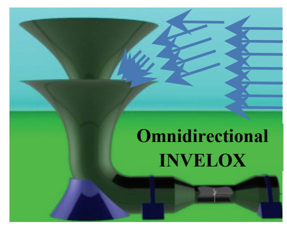


Figure 1 INVELOX system

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.

It is noted that in the case of the traditional wind mill concepts, even though the pressure before and after the turbine is different (i.e. local pressure is impacted), yet the power conversion is proportional to the cubic power of wind speed and square power of blade radius. In other words, pressure in an open flow (i.e. not confined) system cannot be harvested, but it can be influenced. In the case of INVELOX system, the captured wind will be subjected to smaller cross section as they move through the system as

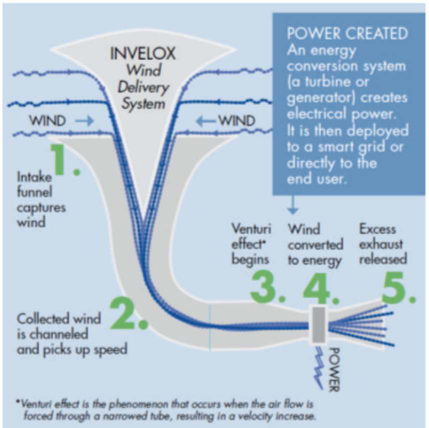


Figure 2 INVELOX system

shown in Figure 2. Eventually, they are put through a Venturi in which an energy harvesting system (i.e. gearless turbine-generator system) is installed. Based on the *Bernoulli* and *Venturi* principals, the wind speeds will increase depending on the cross sectional differences. Since the only energy injected in the system is wind, and mass flow and energy balances, it is the pressure energy that is converted to additional kinetic energy. This process allows the WTG installed in the *Venturi* section to have access to much larger kinetic energy of the wind, and thus be able to generate same or more power using smaller turbines.

INVELOX is based on hydro power approach used for years. The only difference is that INVELOX uses air versus water used in hydro. INVELOX uses the existing kinetic energy and pressure energy in wind while a hydro dam only uses the pressure that is based on water density and gravity. INVELOX does not require huge upfront capital cost that dams require, and INVELOX does not leave a huge negative environmental footprint that dams often build up over years of operations. But from the functionality point of view, they operate in similar manner, and that is how INVELOX can deliver a significantly lower power cost than traditional WTG mounted on a tall tower.

Figure 3 shows the detailed dimensions and geometry of omnidirectional INVELOX modeled using COMSOL-CFD package. This model (INVELOX tower model number M1360-001) uses double nested cone concept with 360 degrees wind intake capability. In addition to having no blade on the top of the tower, this model needs no yaw control to orient the intake into the wind, manually or automatically.

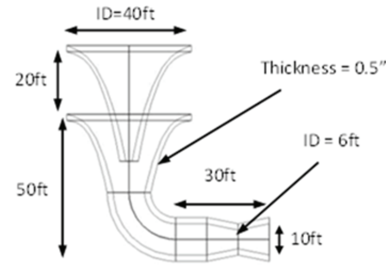


Figure 3 Detailed dimensions and geometry of omnidirectional INVELOX

This model is scaled to fit a 6ft diameter wind turbine at the *Venturi* location, and to be erected to a height of 60ft. Since INVELOX has no hub on the top, the height of the tower is measured from the center of the intake to the ground level. The speed ratio (SR=the free stream wind speed to the wind speed at the *Venturi*), an important design factor, is designed to be about 2. If the free-field wind speed is 15 mph, the speed at the location of the turbine (*Venturi*) will be equal to 2*(15 mph) = 30 mph.

3. Use of COMSOL Multiphysics

Figure 4 shows the INVELOX model created using COMSOL-CFD package. The virtual wind tunnel is the large 200 by 300 by 150 feet rectangular box. Omnidirectional INVELOX is placed at the center of the box while the bottom edge of the system is close to the bottom surface (X-Y plane) of the virtual wind tunnel. The intake is composed of two nested cones. The top cone is the guide directing wind into the lower cone. The CFD model is based on the k-epsilon turbulent flow.

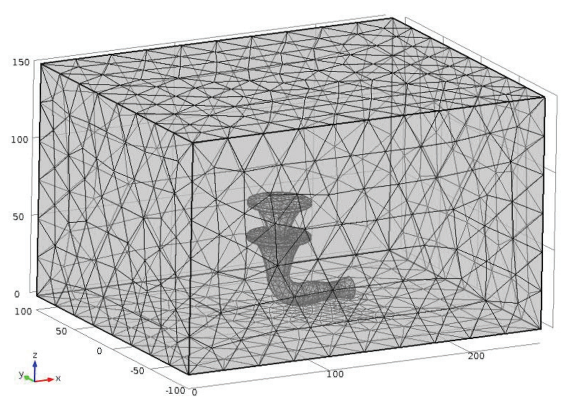
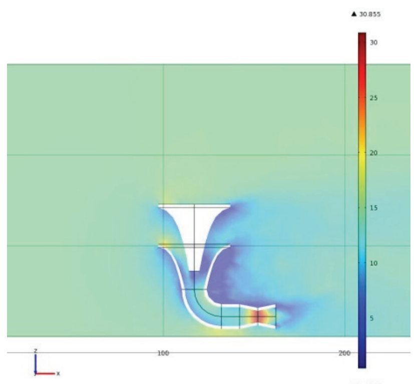


Figure 4 CFD model of INVELOX

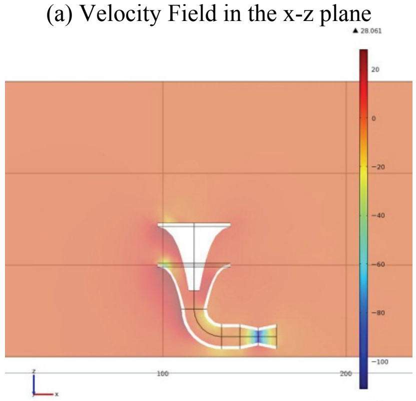
A constant velocity field, representing free stream wind, was assigned to the entire Y-Z plane at X=0. The magnitude of the velocity was set at 15 mph. The entire box was assumed to be at atmospheric pressure. All other five are considered slip walls with exception of the Y-Z plant at X=300ft.

4. Results

Figure 5 shows velocity and pressure fields in the x-z plane at the center of INVELOX. The free stream wind speed is 15 mph in the direction of positive x. No blade is placed inside the *Venturi*. It is noted that while the maximum wind speed reaches 30.9 mph in the *Venturi*, the average wind speed is about 27.3 mph; this results in an average speed ratio (SR) of about 1.82. The pressure field in the *Venturi* reaches a low value of (-111) Pa while the maximum pressure is 28 Pa at the inlet. These results are consistent with *Venturi* and *Bernoulli* principals.



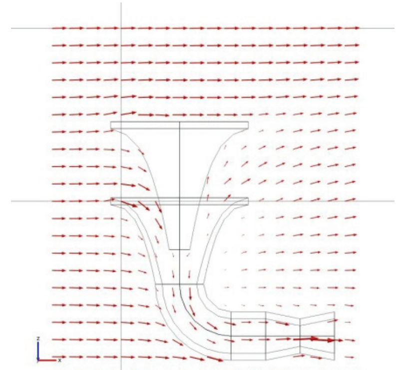
(a) Velocity Field in the x-z plane



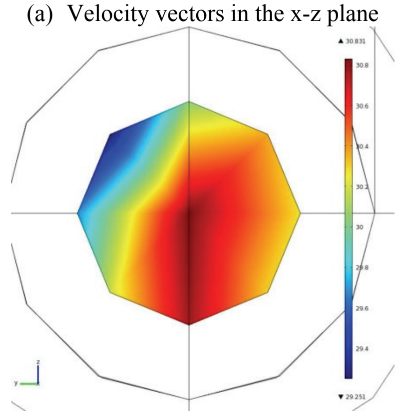
(b) Pressure Field in the x-z plane

Figure 5 Velocity and pressure field in x-z plane at the center of INVELOX

The velocity vectors in x-z plan and velocity profile in y-z plane are shown in Figure 6. It is observed that while most of the vectors point toward negative z direction, some of the wind flows out due to the low back pressure on the other side of the inner cone.



(a) Velocity vectors in the x-z plane



(b) Velocity Profile inside the *Venturi* in y-z plane

Figure 6 Velocity vector and profile

Figure 7 shows the influence of including bars supporting the inner cone on the outer cone. It is shown that average wind speed is practically the same (27.8 mph).

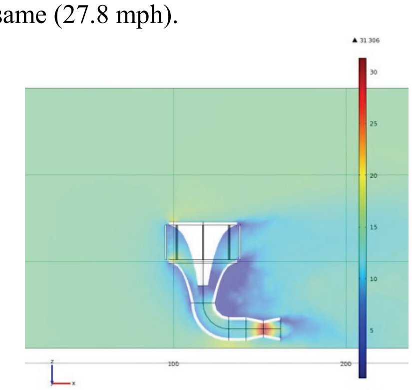
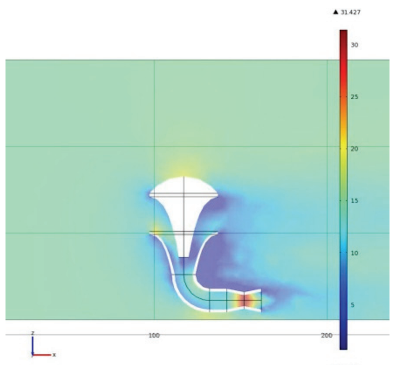
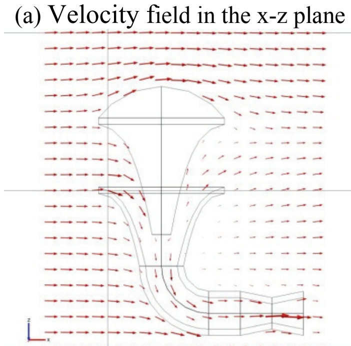


Figure 7 Velocity field in the x-z plane

The influence of a dome on the top of the inner cone is shown in Figure 8. It observed that the maximum velocity increased to 31.4 mph (Figure 8a) while the amount of the wind outflow due to the low back pressure was slightly decreased. In order to increase the wind speed at the Venturi, where the turbine will be mounted, four fins (or partitioned) were placed at 90 degrees apart between the inner and outer cones. Figure 9 shows an omnidirectional INVELOX with four fins placed at 90 degrees apart. The fins are also used as the supporting structures holding the inner cone.



(a) Velocity field in the x-z plane

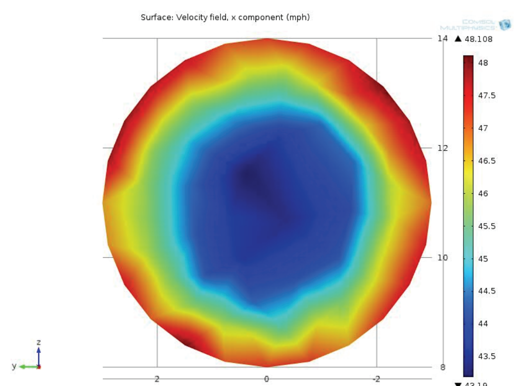


Velocity vectors in the x-z plane

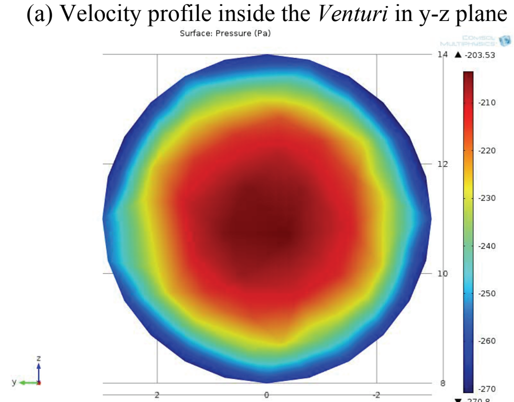
Figure 8 Influence of a dome top on the velocity fields of INVELOX

Figure 9 Omnidirectional INVELOX with four fins distributed 90 degrees apart

Figure 10 shows the velocity and pressure profiles at a cross sectional area inside the *Venturi*. It is noted that the average velocity was raised to more than 45 mph, while the maximum velocity was increased to more than 48 mph, speed ratio of more than 3. In other words, adding the passive fins between the inner and outer cones, increase speed by 60%. Since power is proportional to cubic power of wind speed, 60% increase in wind speed, means power output is increased by 5 times. In addition, the velocity profile is much more uniform with high velocities at the edge of the blade and lower velocities near the hub. This velocity profile is more effective for harvesting wind power. In Figure 10b, the pressure profile is displayed. As it was expected, the pressure profile of the same cross section in the *Venturi* is shown that the pressure drop is much greater than the INVELOX with no fin.



(a) Velocity profile inside the *Venturi* in y-z plane



(b) Pressure field inside the *Venturi* in the y-z plane

Figure 10 Velocity and pressure field in y-z plane inside the *Venturi*

5. Conclusions

It was shown that INVELOX can be designed to capture and accelerate wind to speed ratios of 2 and 3 for omnidirectional INVELOX without and with fins, respectively. Increasing wind speed by a factor of 2 or 3, results in increased power output by a factor of 4 to 8. It was further shown that COMSOL is an effective computational tool to model and analyses the performance of INVELOX systems.

6. References

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7. Acknowledgements

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