2. My research / work at THI

a. What was realized / Results of the research stay (can be a presentation as well)?

INTRODUCTION

Wind energy is one of the most important types of renewable energy resources. The increase of environmental awareness and the shortage of fossil fuels make the renewable energy market grows. Therefore, wind turbines and wind farms are growing as well.

A wind turbine is a device that extracts kinetic energy from the wind. By removing some of its kinetic energy the wind must slow down but only that mass of air that passes through the rotor disc is affected. As the air passes through the rotor disc, by design, there is a drop in pressure such that, on leaving, the air is below the atmospheric pressure level. The air then proceeds downstream with reduced speed and pressure: this region of the flow is called wake.

Source: (JENKINS et al., 2001)

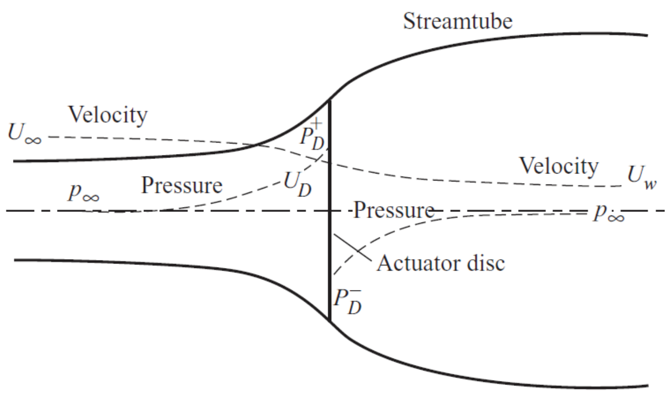

Figure 1 - Actuator Disc and Variation of velocity and pressure.

To design and control superior performing, less maintenance-intensive wind farms, the interaction between the Atmospheric Boundary Layer - ABL, the turbines, and their wakes needs to be better understood.

There are currently two main work fronts for wind energy using Computational Fluid Dynamics - CFD. The first front focuses on simulating just one turbine alone in the most accurate way, and the second front focuses on improving wind farm predictions, where the simulation includes several turbines. In the latter, the actuator disk model is applied, and there is also a concern about how the complex terrain influences the efficiency of the wind farm's turbines. The main objective of my work is to simulate a real farm with several turbines using actuator disc and complex terrain.

METHODOLOGY

The present study focuses on the numerical investigation of the wake development in horizontal axis wind turbines (HAWT). A model of a wind turbine from the Beberibe wind farm was studied as a uniform disk, which creates a discontinuity of pressure in the stream tube of air flowing through it. With this model, called actuator disc model, we can begin an analysis of the aerodynamic behavior of wind turbines without any specific turbine design just by considering the energy extraction process.

The Beberibe wind farm, located in the city of Beberibe in the state of Ceará/Brazil, has been in operation since April 2009. It consists of 32 wind turbines of the E-48 model (rotor diameter 48 meters and nacelle height 75 meters), produced by the manufacturer Wobben, with a power of 800 kW each.

Figure 2 - Beberibe Wind Farm, extracted from Google Earth™

The flow in the rotor wake is highly turbulent with large-scale turbulent structures. If another wind turbine operates in this wake, its blades will be subjected to unsteady aerodynamic forces and that will lead to the decreasing of blade fatigue life.

The actuator disk gives a good result for the far wake, where the individual presence of the blades becomes small and therefore can be neglected. However, if a detailed representation of near wake or blade tip vortices is needed, a three-dimensional model for each blade must be used.

The numerical model was implemented in commercial CFD code ANSYS Fluent. CFD simulations are viscous and unsteady and use the Reynolds-averaged Navier-Stokes (RANS) approach.

In March and April of 2020, a literature review of the actuator disk model in wind turbines using CFD simulations was made.

From April to June, the numerical model was developed for the case of a single wind turbine installed on flat terrain considering the inlet atmospheric boundary layer. The domain is represented in Figure 3.

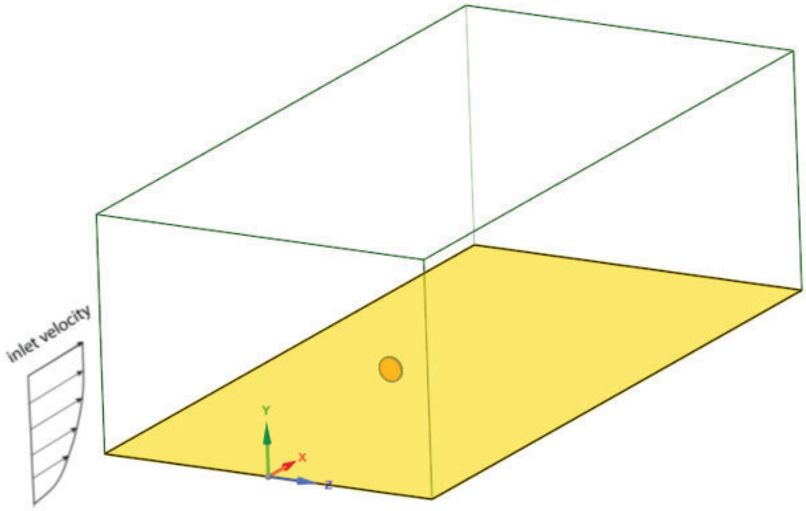

Figure 3 - Computational domain: actuator disk in an enclosure with varying inlet velocity.

The computational domain, with more specifications represented in Figure 4, had length of 30D, width of 15D and height of 10D, where D is the rotor diameter, 48 meters. The nacelle height, here represented by the center of the actuator disk, is 75 meters. The nacelle and mast were not modeled.

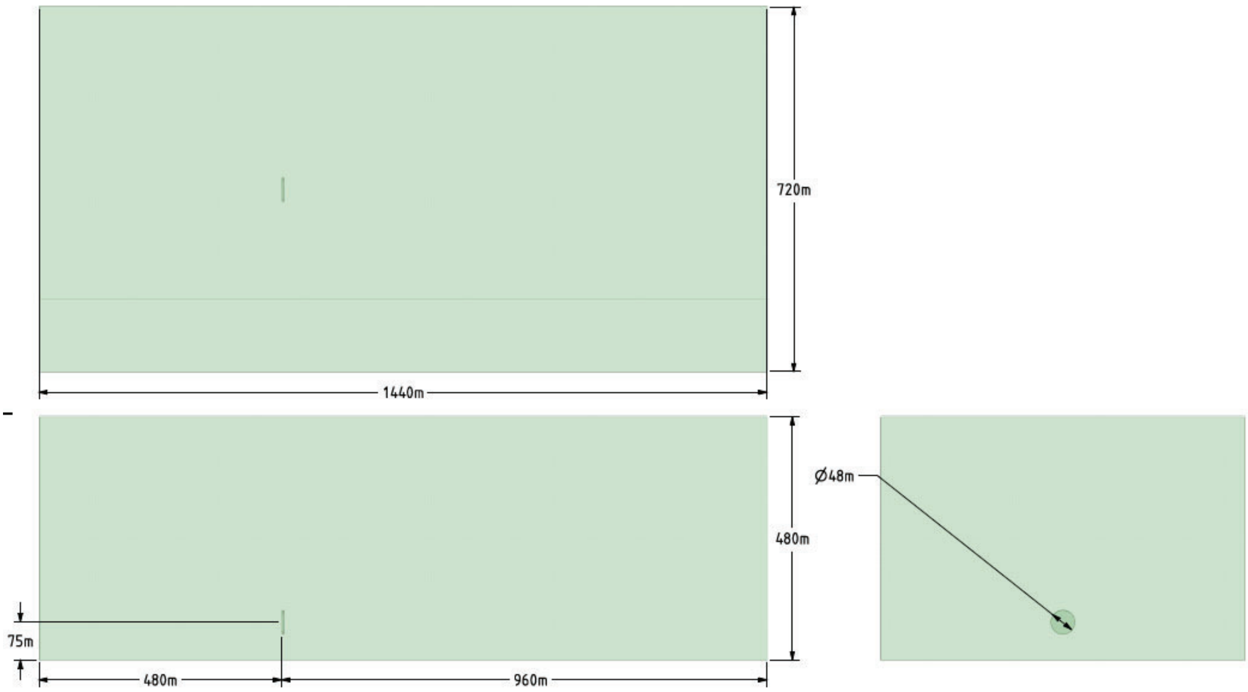

Figure 4 - Computational domain with dimensions.

From July to September, the numerical model was developed for the case of 12 wind turbines installed in the real complex terrain of the Beberibe Wind Farm. Due to computational demand, this research only studied a part of the whole Wind Farm. Even though applying only a part of the farm, the objective of simulating a real farm with several turbines using actuator disc and complex terrain was reached as the behavior of the wind flow around and through the wind turbines was compared to the fundamentals of wind turbine aerodynamics.

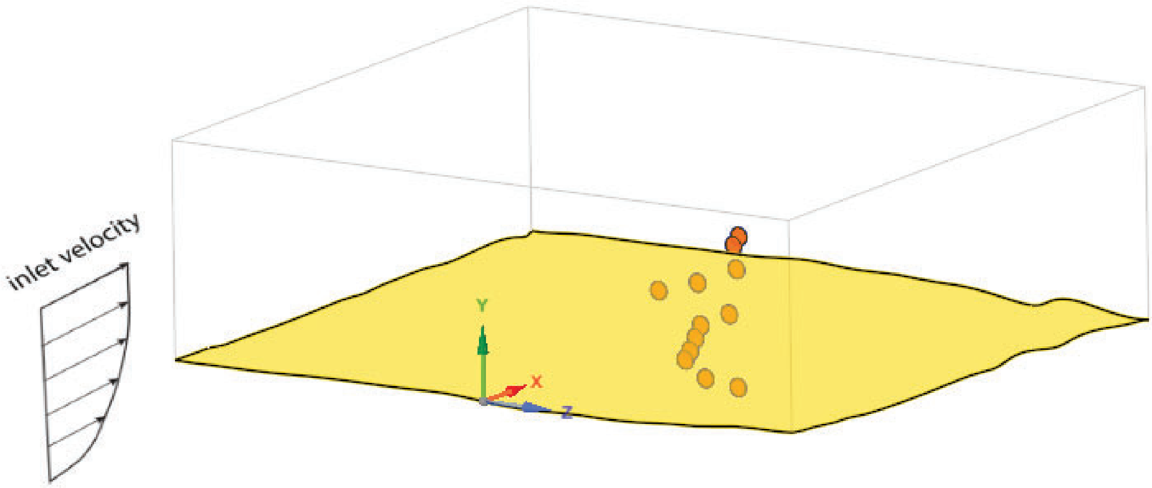

Figure 5 - Computational domain: 12 actuator disks in an enclosure with varying inlet velocity.

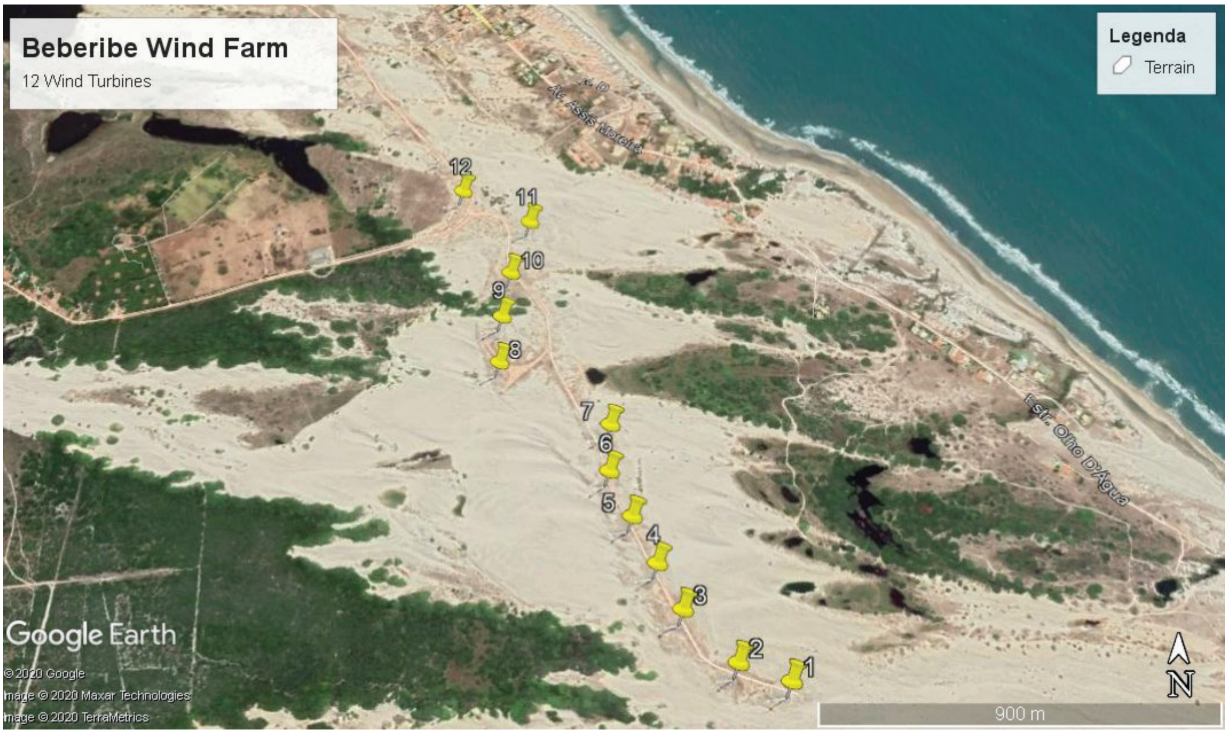

Figure 6 - Location of studied Wind Turbines.

RESULTS

The main results are related to the velocity and pressure of the fluid flow in the wind farm. With these results, it is possible to verify how the wind flows due to turbulence. Applying the conditions of Atmospheric Boundary Layer (variation of inlet velocity), the right turbulence model, and the shear condition of no-slip on the ground, the results are obtained, see Figures 7-12 for the first case (one actuator disk and flat terrain) and see Figures 13-17 for the second case (12 actuator disks and a portion of the complex terrain of Beberibe Wind Farm).

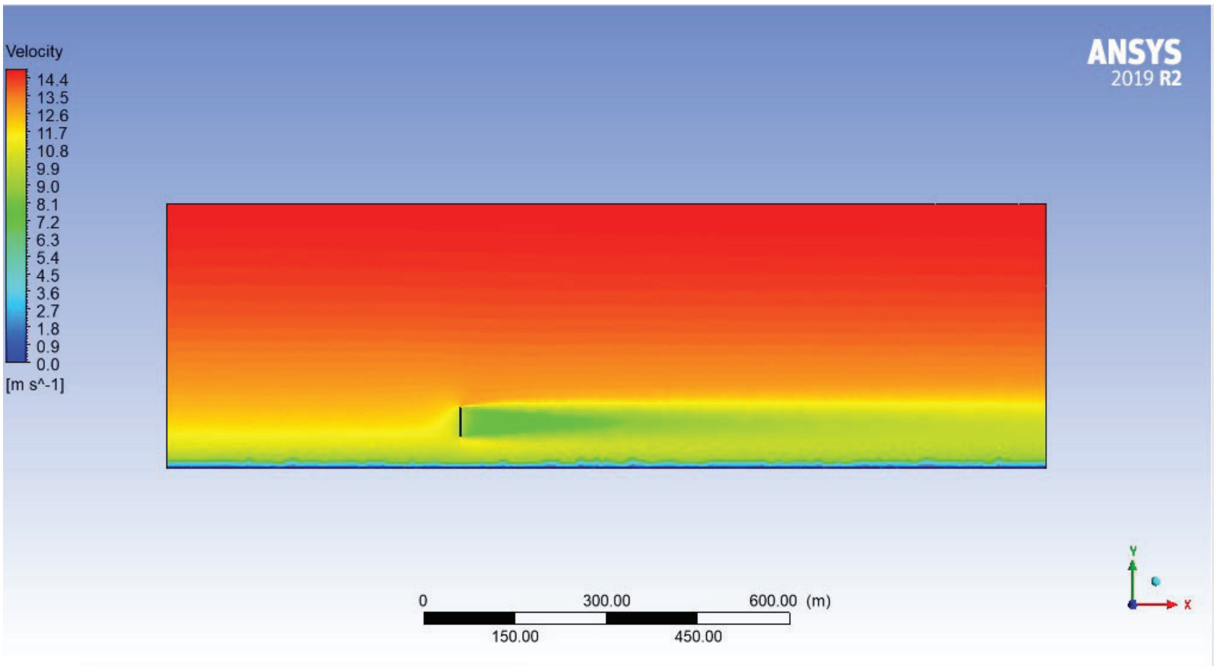

Figure 7 - Velocity contour (side view) – case 1.

Applying a line to extract data source from the inlet domain to the outlet domain passing through the center of the actuator disk, the velocity can be represented in the chart (Figure 8).

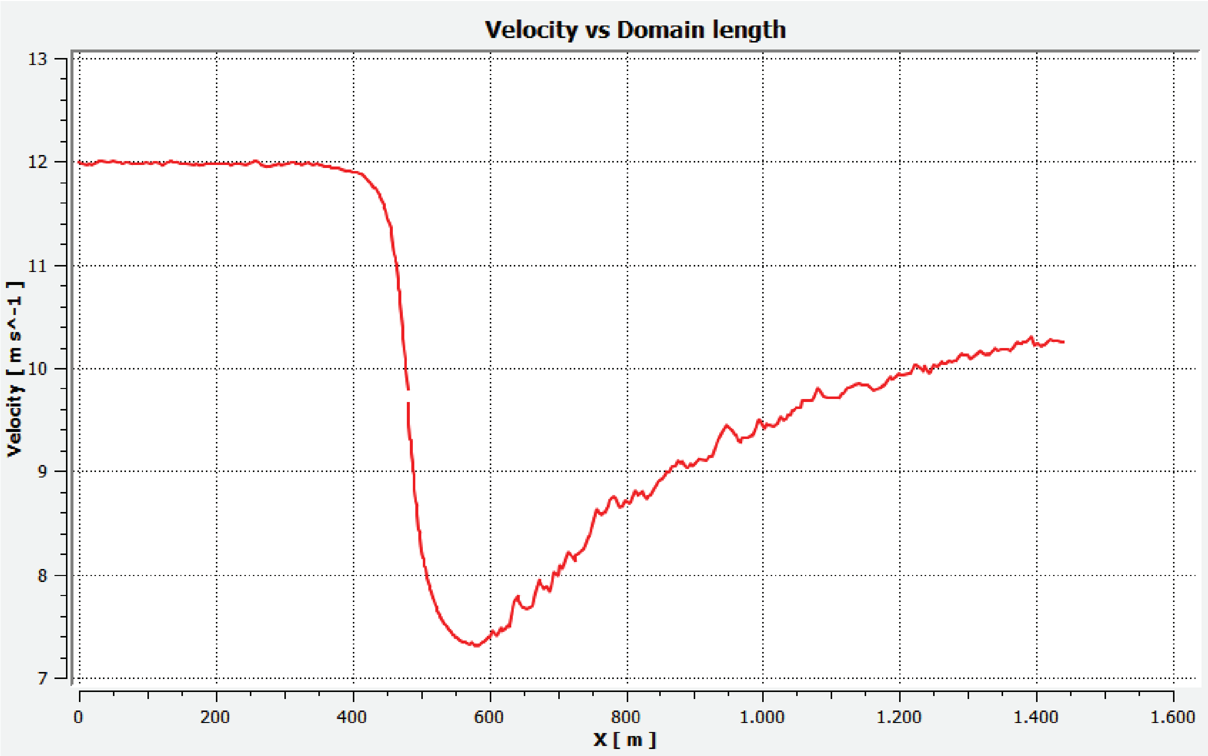

Figure 8 - Velocity in domain length.

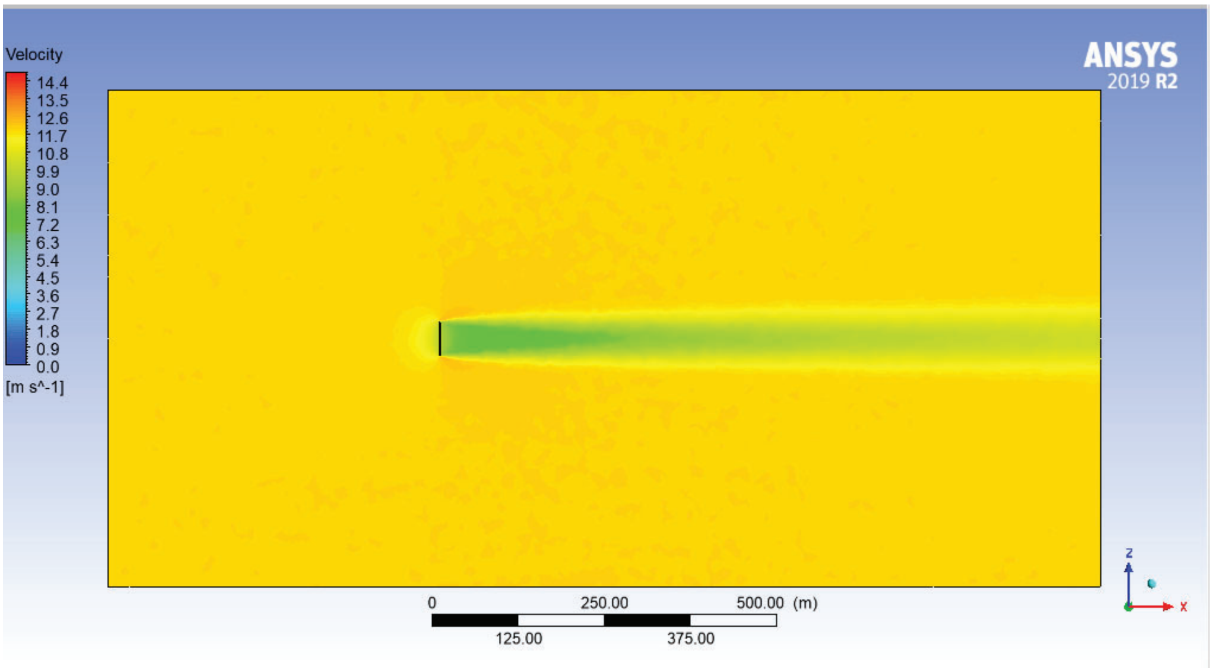

Figure 9 - Velocity contour (top view) – case 1.

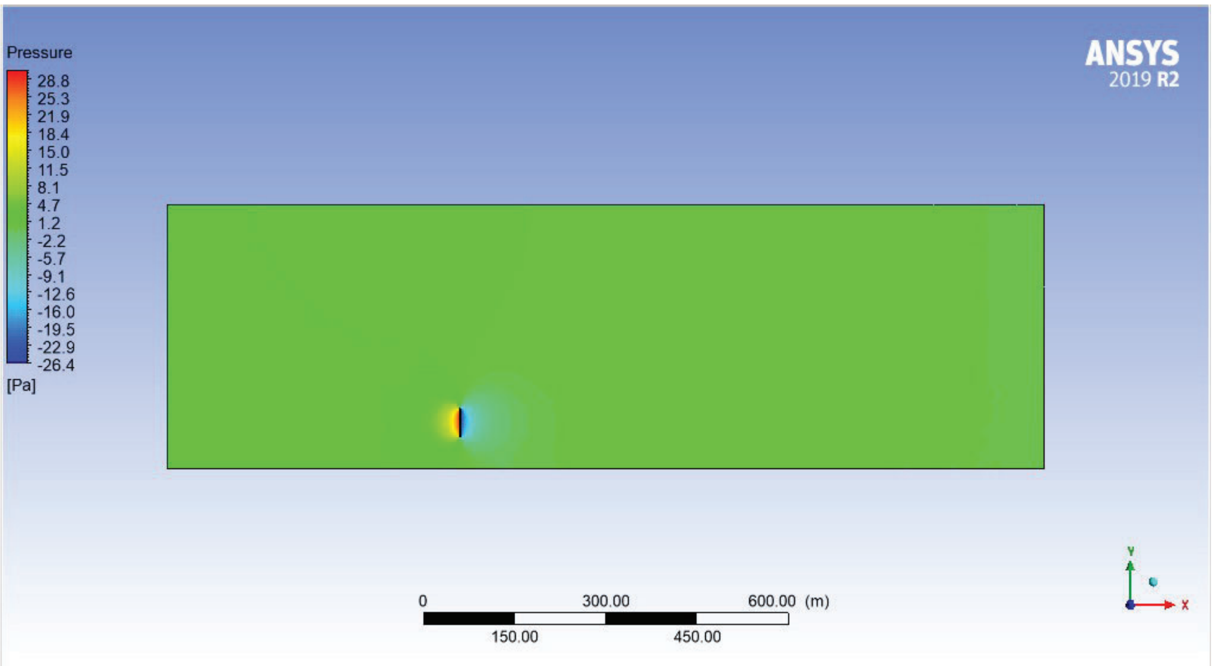

Figure 10 - Pressure contour (side view) – case 1.

With the same line from the inlet domain to the outlet domain passing through the center of the actuator disk, the pressure can be represented in the chart (Figure 8).

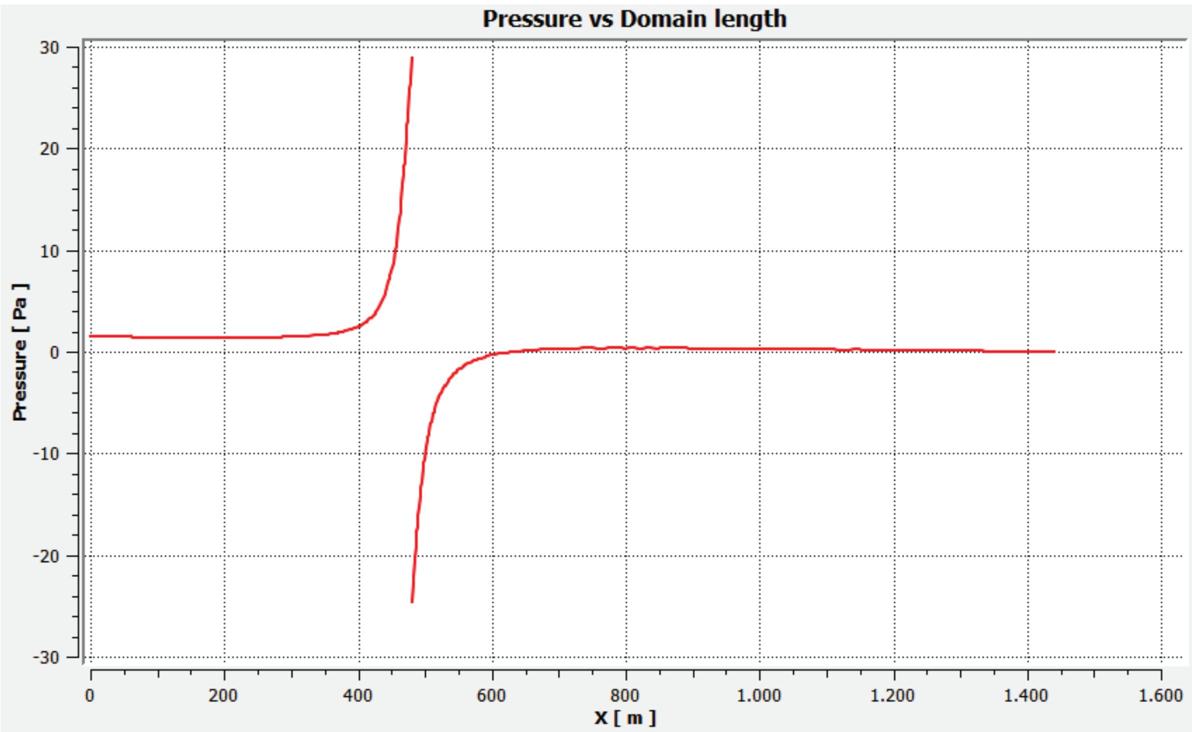

Figure 11 - Pressure in domain length.

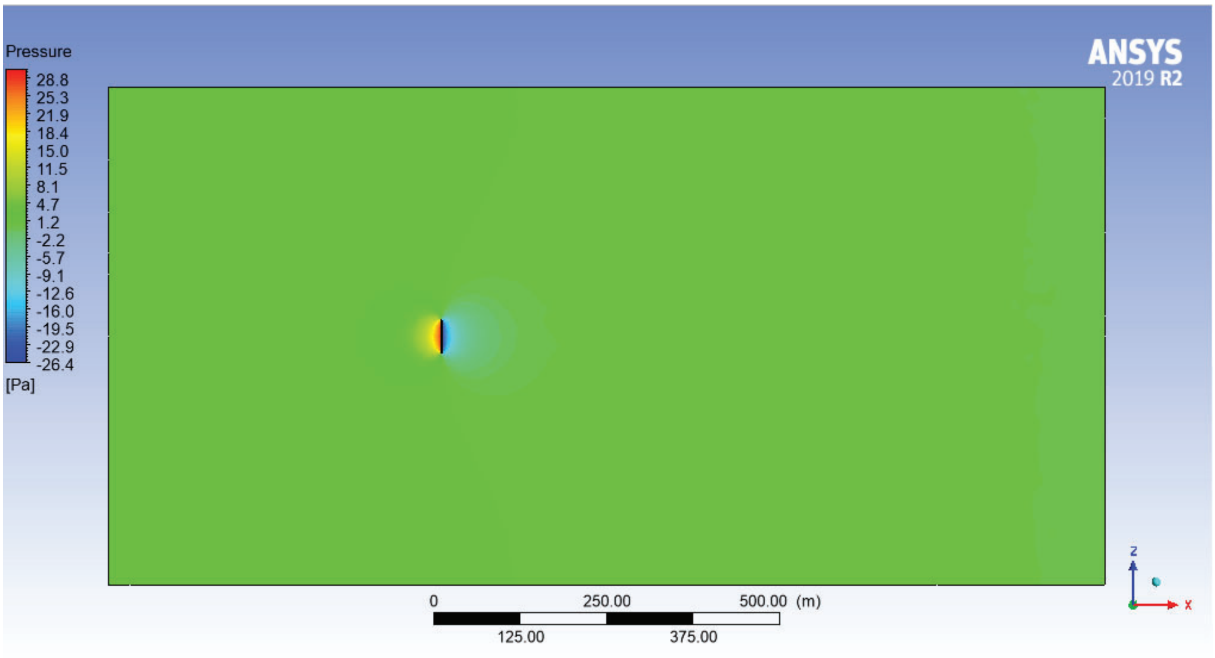

Figure 12 - Pressure contour (top view) – case 1.

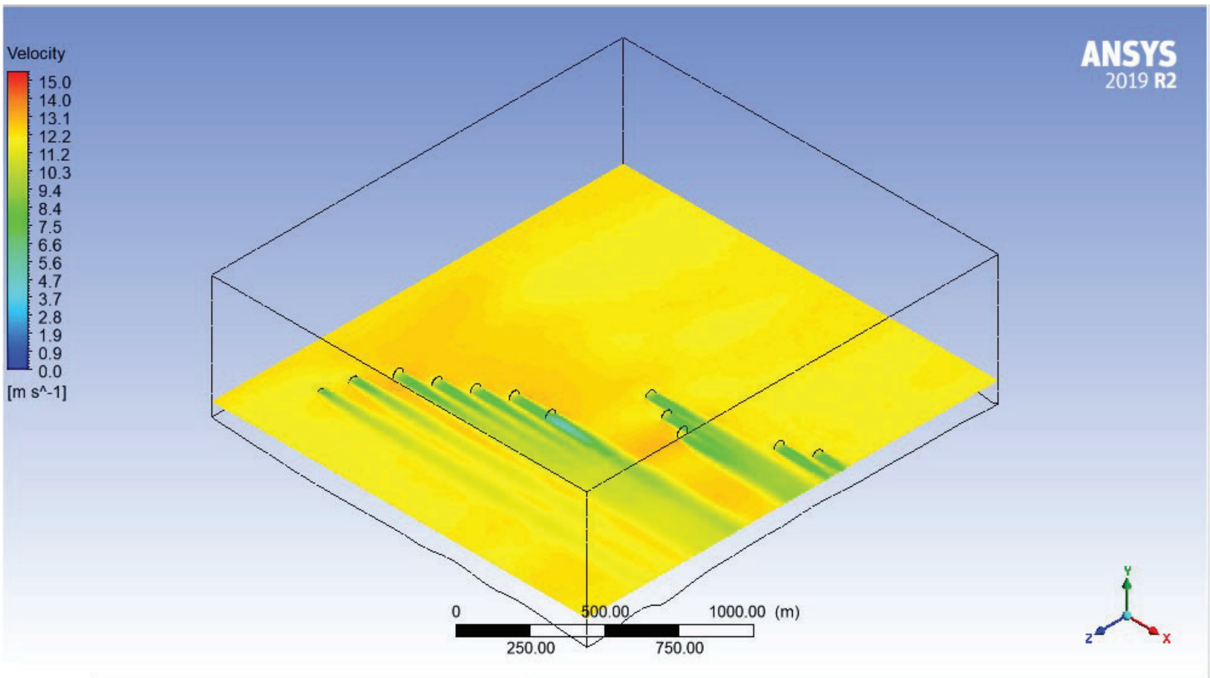

Figure 13 - Velocity contour (isometric view) - case 2.

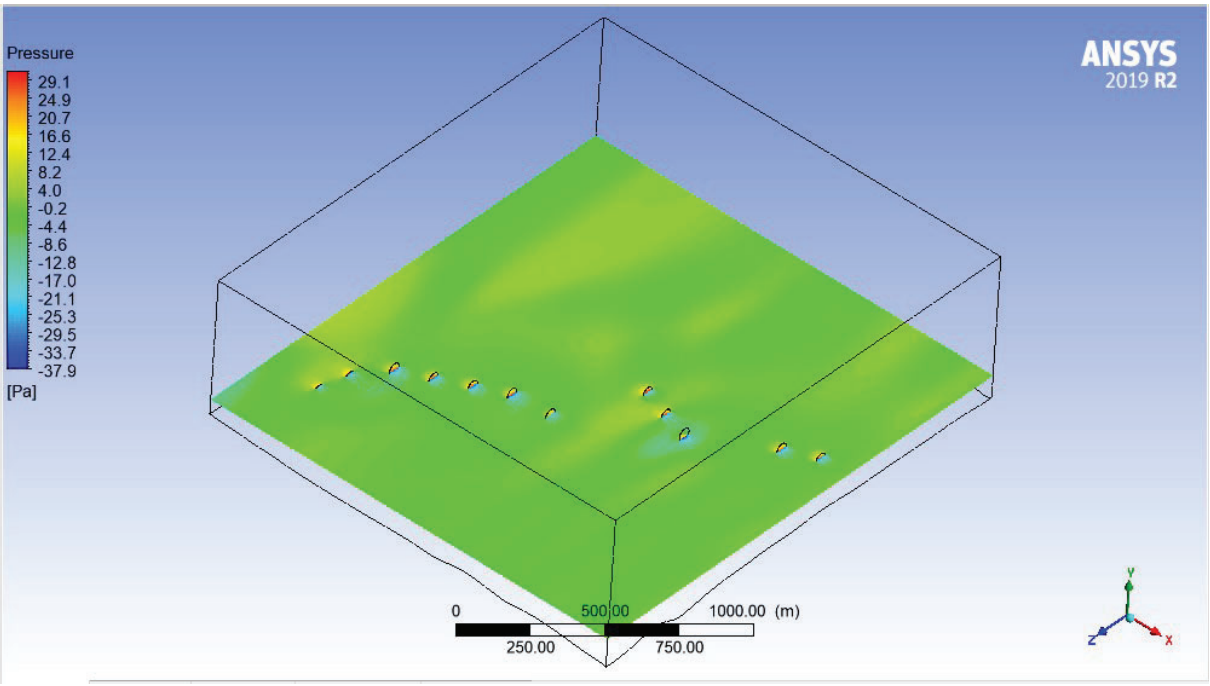

Figure 14 - Pressure contour (isometric view) - case 2.

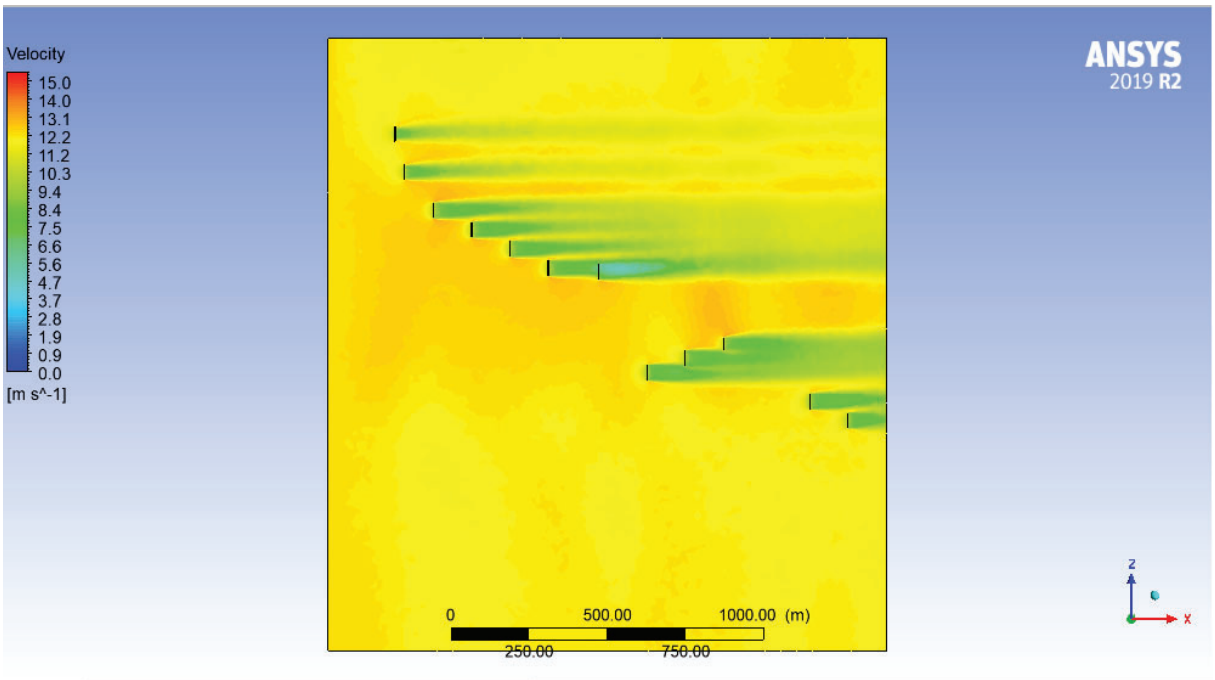

Figure 15 - Velocity contour (top view) - case 2.

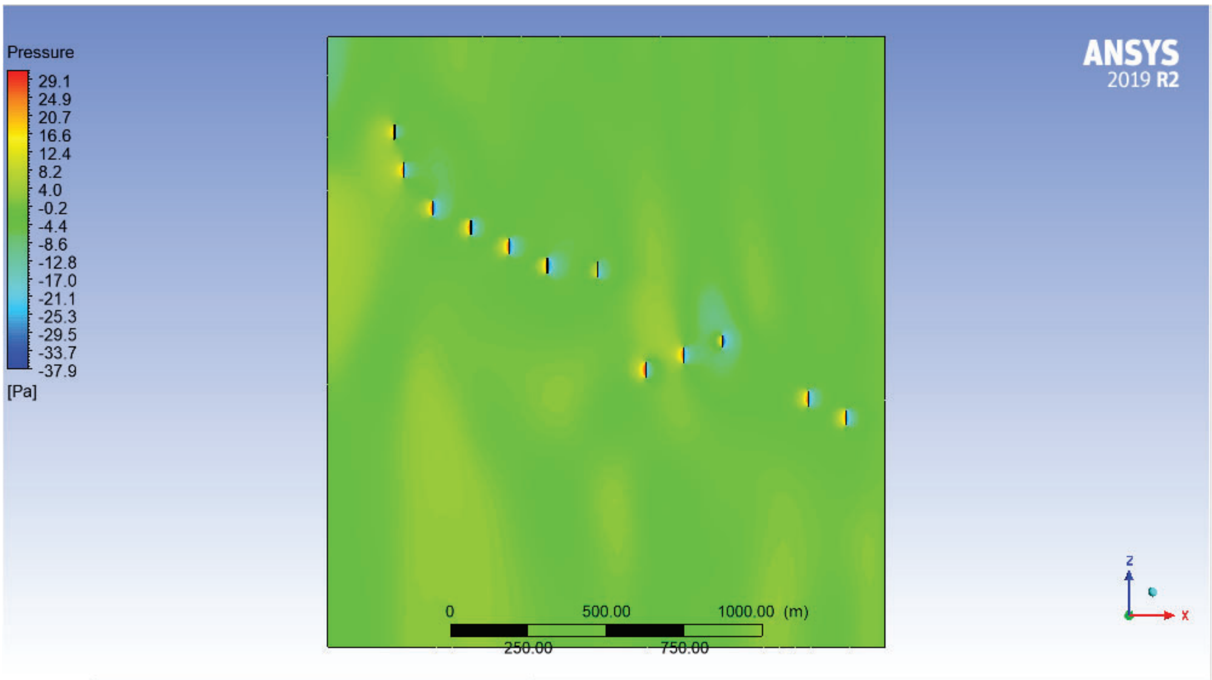

Figure 16 - Pressure contour (top view) - case 2.

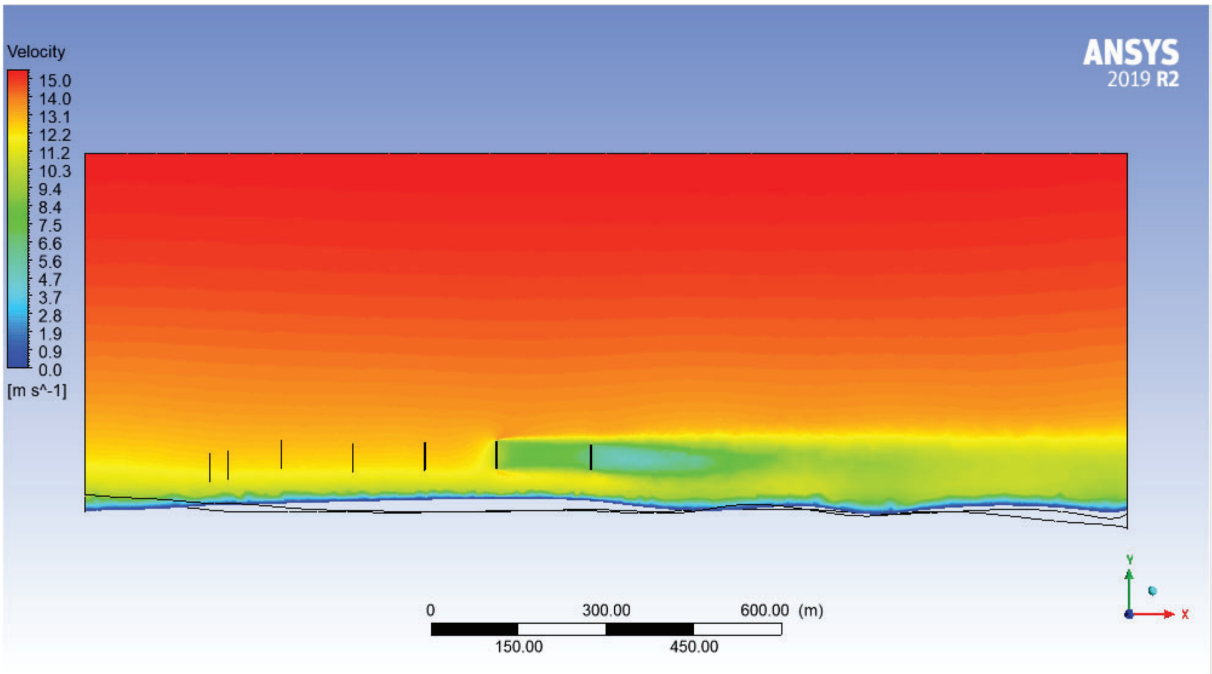

Figure 17 - Velocity contour of Wind Turbines 6 and 7 (side view) – case 2.

In consideration of the wind turbine 7 is located behind wind turbine 6, it is revealed that the velocity of the flow upstream the turbine 7 is less than the turbine 6. Consequently, the power production of turbine 7 will be affected.

CONCLUSIONS

Using CFD, the actuator disk model was applied for two different cases of this research. The first case was to investigate a single wind turbine installed on flat terrain considering the inlet atmospheric boundary layer. This simulation was used to understand and apply the appropriate mesh generation, the calibration of the turbulence model, the proper boundary conditions and the physics involved.

There is also a concern about how the complex terrain influences the efficiency of the wind farm's turbines. For this reason, a section of a real wind farm with twelve turbines using actuator disc and complex terrain was modeled.

There are evidences that the complex terrain contributed to insert different pressure drop inducing disturbances in the free flow upstream which will lead loadings to the wind turbine blades. The interaction between the disturbances in the flow field caused by the terrain and by the turbines is important to predict maximum Annual Energy Production (AEP) accordingly to the site layout.

b. Will the project be continued after your stay at THI?

Yes, the project will be continued after my stay at THI. With the use of the facilities of THI, it was possible to run the calculations with excellence. These simulations will be useful to substantiate my master’s thesis. To complete the research, the following steps must be done:

- Apply the real wind flow conditions (wind directions and wind velocities) according to the Wind Rose of the Beberibe Wind Farm.
- Layout optimization of the wind farm.
- Write the thesis with everything calculated by simulations during the stay at THI.

REFERENCES

JENKINS, N. et al. Wind Energy Handbook. United Kingdom: John Wiley & Sons Ltd, 2001. ISBN 0-4714-8997-2.