18th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2014, Budapest, Hungary, 10-12 September 2014

OPERATION OF A SMALL WIND TURBINE WITHIN URBAN AREA

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ABSTRACT

While the rapid development of huge on- and off-shore wind farms continues, examples of integration remain scarce within urban environments, closer to prime consumers of energy such as buildings. Successful integration would require developers to fully address the concerns of planners, pressure groups and the public as to the necessities and environmental impacts of such schemes. This paper addresses the possibilities of exploiting architectonic barriers for improving the effectiveness of wind turbines within an urban environment. 3D CFD simulations using ANSYS CFX 13 solver were carried out for this purpose. The aim of these simulations was to predict pressure and velocity fields at the top of a building within an urban area in order to find the optimal position for the placement of a small scale wind turbine on the roof of the building and to evaluate any possible surcharges for harnessing energy. The study confirmed that wind energy can also be effectively used within urban environments. The CFD simulations indicated that a building placed at a specific location would have a positive impact on wind spreading conditions and would subsequently enhance the effectiveness of the wind turbine, but increased turbulence and velocity gradient would call for careful choice of turbine type and its optimal position.

Keywords: wind turbine, urban area, CFD simulation

1. INTRODUCTION

The world has experienced very fast growth of wind farms over the last decade. Every year, the number of newly-installed wind turbines increases exponentially [1]. However, most of them are built far from urban areas where most of the produced electricity is spent. Generating energy from the wind within an urban environment is mostly being overlooked, although it places a source of supply at a site of strong energy demand and thus fulfils the essence of embedded generation.

There are three possible strategies for the practical implementation of wind turbines within an urban area [2]. The identified three possible strategies are:

- simply siting (landscaping) conventional free-standing wind turbines within an urban environment;
- retro-fitting wind turbines onto existing buildings;
- integration of wind turbines within buildings that are specially designed for the purpose.

The last concept is quite complex and may involve comprehensive studies regarding the aerodynamic performances of buildings' forms for optimal turbine integration. On the other hand, fitting the landscaping and retro-fitting wind turbines within urban areas may be quite straight forward when considering specific urban conditions [3].

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2. SIMULATION OF A FLOW AROUND THE BUILDING

Buildings, trees, noise barriers and other obstacles influence the wind flow and create local, micro wind regimes with more turbulence and gusts. Due to the influence of surrounding buildings, it is important to place the wind turbine on the highest building in the area and to ensure that there are enough distances from other high buildings. This fact simplifies the simulation, as the influence of the surrounding buildings and other obstacles of moderate height may be modelled as increased terrain roughness with a specific velocity profile [4]. It was assumed that the wind speed would be zero at a height δ, defined as 0.75 of the average height of structures within a given area. Two building geometries: simple block and a sloped building (Fig. 1) both with a flat rooves were analysed and compared.

a) block building b) slope building

Figure 1. Block (a) and slope building (b)

The flow around the specific building was simulated by 3D CFD simulations using an ANSYS CFX 13 solver. The aim of the simulations was to predict the exact velocity field around the building and especially on the roof, in order to predict those zones of high turbulence intensity and velocity gradients that could be problematic for micro turbines. The computational domain for a simple block building (20 x 20 x 40 m) is presented in Fig. 2. It is 401 m long, 200 m wide, and 200 m high. A non-structured mesh was used with 1.3 million elements. Special care was taken to condense the computational mesh around the building and to properly model the boundary layer at the building's walls. The latter was achieved by so-called inflation boundary layer meshing.

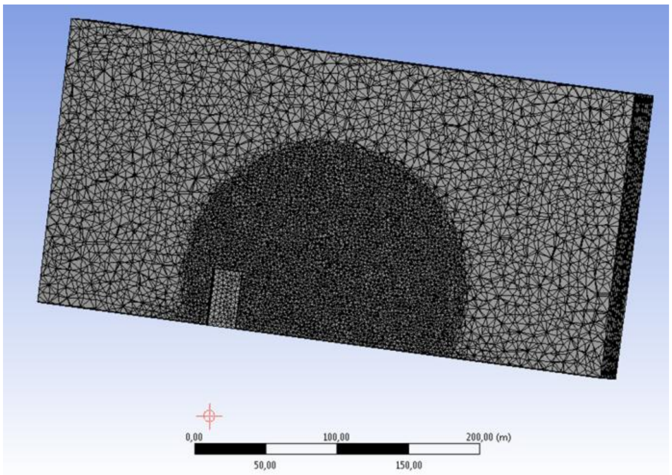

Figure 2. 3D computational mesh – simple block building

At the intake boundary, the velocity profile characteristic for city centre location conditions [2] was prescribed, whilst the boundary condition 'opening' was applied for other open surfaces of the computational domain. The 'no slip wall' boundary condition was used at the virtual ground (elevated by δ from the actual city ground) and at the building's walls. All the simulations presented in this paper were done using a SST turbulent model.

3. RESULTS

The power of the wind can be expressed as:

$$P_w = 0.5 \cdot \rho \cdot A \cdot v^3 . \qquad \text{... (1)}$$

where P_w = the power of the wind, ρ = air density, A = swept area of rotor, v = wind speed. A wind turbine is only able to remove some of the power available from the wind because the air needs to continue to pass through the turbine for it to operate, thus limiting the kinetic energy available for extraction. The theoretical limit on the fraction of power that can be removed from the wind is 0.593 (Betz number). Practical wind turbines extract less power than is ideal. The so-called power coefficient C_P is used to express how effective a turbine is at extracting power. It is defined as a ratio of the power from a turbine to the power available from the wind:

$$C_P = \frac{P_T}{0.5 \cdot \rho \cdot A \cdot v^3} . \qquad \text{... (2)}$$

where P_T = power from a turbine. The C_P for particular turbines vary with the ratios of rotor speed to wind speeds, however disordered flow conditions such as increased turbulence intensity and velocity gradients may reduce it significantly. As follows from equations (1) and (2), the turbine power increases with the third power of wind speed, thus the optimal placement of the turbine should coincide with the local velocity maximum. This may be found from the predicted velocity field shown in Fig. 3. As can be seen there is a significant increase in local velocity by approximately 1 m/s at the front edge of the roof. The question is, however, whether flow conditions correspond to the high power coefficient. In order to answer this question the turbulence intensity field at the roof of the building should be inspected.

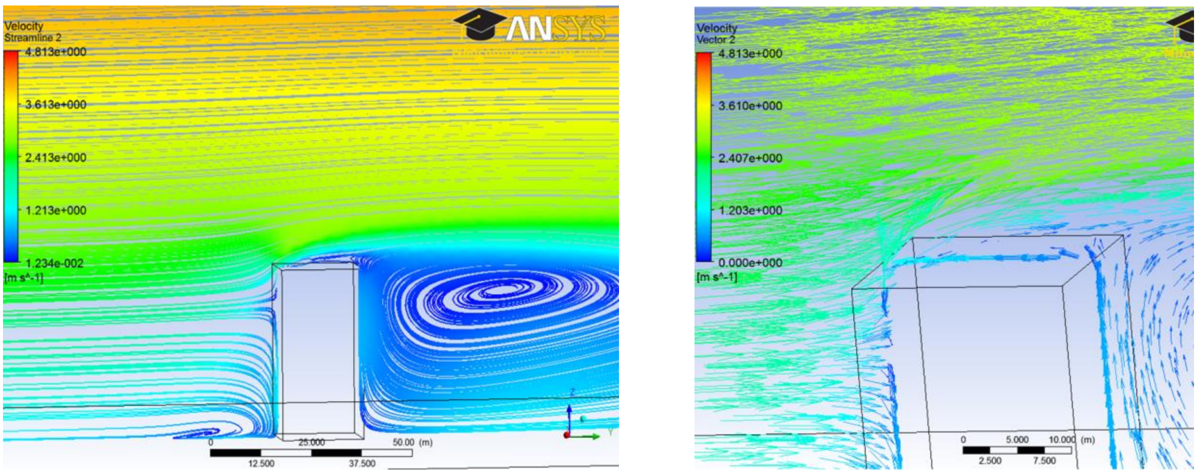

Figure 3. Predicted velocity field – simple block building

Figure 4 shows the predicted turbulent kinetic energy. It increases significantly after the wind passes the building and a large vortex is formed behind the building. The latter influences a modest reverse-flow near the roof's wall (Fig. 3) and increases the turbulence intensity at the roof of the building. In order to avoid both the high velocity gradient at the front side of the roof and the increased turbulence intensity near the roof, the wind turbine should be placed about 8 m from the front side of the roof and well-above it (5 m), as shown in Fig. 4. This will ensure a high yield of wind energy (velocity is increased from 2.5 to 3.5 m/s, whilst the power of the wind is increased by more than 250%) with only a modest reduction of the power coefficient due to the increased turbulence intensity and velocity gradient. The vertical axis turbine is preferable, as it better adapts to changeable wind direction.

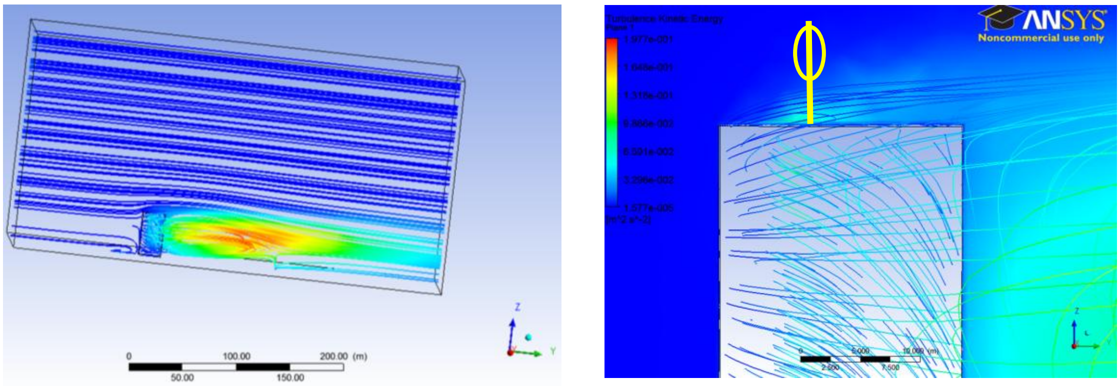

Figure 4. Predicted turbulence kinetic energy field – simple block building

A sloped building on the side of the prevailing wind direction can have a positive effect on the energy yield of a wind turbine. Therefore, a similar simulation was conducted for a building with a 30 ^{0} slope of the front wall. Some of the predicted results are shown in Fig. 5. Similar velocity increase was observed at the front side of the roof. However, in comparison with the block building the velocity gradients were lower, as well as the turbulence intensity near the roof being smaller. Thus the turbine could be placed at the front edge of the roof where the conditions for wind energy yield are the best because of the positive pressure gradient established along the sloped front wall.

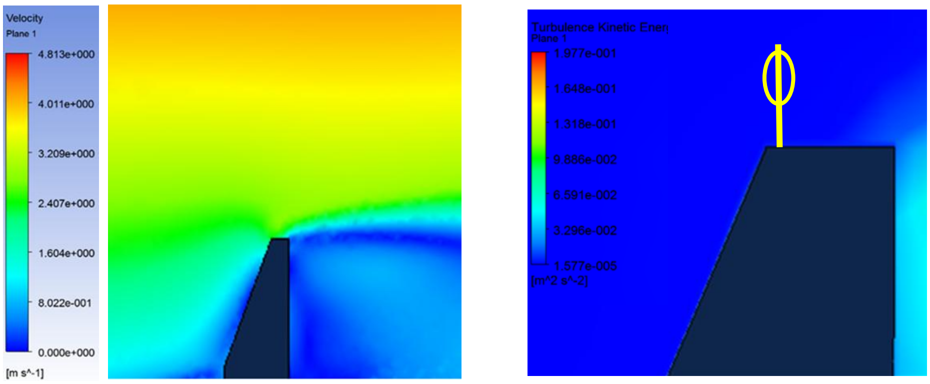

Figure 5. Predicted velocity and turbulence kinetic energy fields – sloped building

4. CONCLUSION

This study presented the optimization of a wind turbine's position on the roof of a building within an urban area. 3D CFD simulation using an ANSYS CFX 13 solver was used to predict the pressure, velocity, and turbulence intensity fields at the top of the building where a small scale wind turbine should be placed. The study confirmed that wind energy could also be effectively yielded within an urban environment. The CFD simulation indicated that a building placed at a specific location would have a positive impact on wind spreading conditions and subsequently locally enhance the power of the wind by approximately 250%. However, increased turbulence and velocity and pressure gradients call careful choosing of a turbine's optimal position in order to preserve the high power coefficient.

5. REFERENCES

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