Performance Analysis of Vertical Axis Wind Turbines in the Urban Environment

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Introduction

A joint research effort between McMaster University and Cleanfield Energy has been undertaken to investigate the implications of mounting vertical axis wind turbines (VAWT) on buildings in urban environments. Implementing turbines in urban environments raises a number of unique issues that are not present in typical wind turbine installations. These issues are the complex flow structures over buildings, high turbulence intensity and variable wind speeds and directions. Due to the VAWT's inherent operation they do not suffer in performance due to increased turbulence and harness all of the wind independent of fluctuations of direction. This makes the application of these turbines feasible and practical for rooftop applications.

Flow around buildings is very complex, as it contains regions of flow separation and reattachment as well as standing and rolling vortices. These flow structures are depicted below in the computational fluid dynamic simulation of wind flowing over a building in the atmospheric boundary layer (Figure 1). These flow structures are further complicated by the urban environment and angled incident flow to the building faces.

The objective of this investigation is to determine how the flow conditions on the roof of an urban building affect the performance of a vertical axis wind turbine. The present work pertains to a steady state comparison between the "clean air" wind tunnel results and the quasi steady "dirty air" rooftop results.

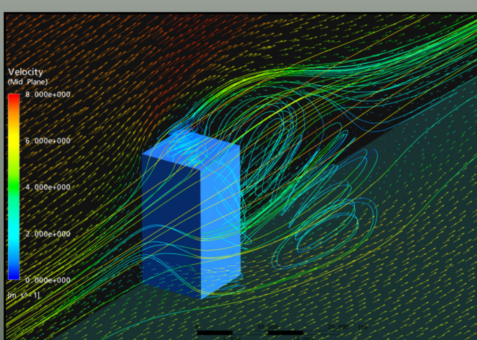

Figure 1: Numerical modelling of a building with normal flow to the building's face.

Uniform Steady Wind Performance

Wind tunnel testing has shown the turbine performance without the influence of the urban environment. Power curves from these uniform flow "clean air" tests provide a benchmark for comparing data from the "dirty air" urban mounting configuration. Turbulence fluctuations in the wind tunnel tests were less than 2%. Substantial subsequent modifications to the turbines strut cross section were carried out, increasing the overall performance of the turbine. The losses in the system were quantified prior to and after alterations, allowing for appropriate modifications to the wind tunnel performance curves. (Figure 2)

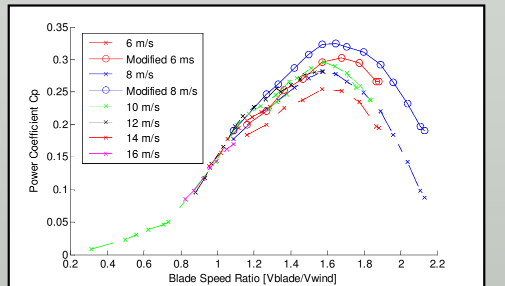

Figure 2: Performance curves for steady uniform wind conditions with the superimposed modified curves.

Experimental Details

Two experimental wind turbines are located at McMaster Innovation Park, a medium rise, four-story building located in an urban/industrial setting. One of the two 3.5 kW turbines is mounted on a stationary frame located near the corner of the building exposed to the prevailing wind direction, while the other is installed on a 2.5 metre high mobile tower. This allows for the turbine to be relocated on the roof and capture various wind distributions over the building. The power generated by the turbine is harnessed by means of a mechanical disk brake. A load cell placed on the brake records the forces applied so that the power absorbed can be deduced. The turbine is controlled through a closed loop constant RPM controller. Traversing anemometers, positioned at mid turbine height, 4 metres, and a reference anemometer 8 metres high, are situated to record the flow velocity and direction into the turbine.

Transient Rooftop Results

As expected, the RMS of the wind speed and direction is much higher than what a turbine would typically encounter in rural applications (Figure 3). The transient nature of the turbine can be seen in the power wind speed relationship. With the variation in wind speed, the power lags due to the inertial energy stored in the turbine (Figure 4). This delay is compounded by the lag in the aerodynamic behavior of the turbine as well as the lag in wind readings measurements. Without taking these considerations into effect, the performance from the averaged signals would be inaccurate. Using a loose signal conditioning criteria, only the data where the wind speed is satisfactory to hold the turbine at its RPM set point, yields the valid transient performance points (Figure 5). Applying selective criteria to the standard deviation of the rpm and the wind conditions make it possible to retrieve the points that are at relatively steady state (Figure 6). These steady state points from the field data yield similar results as to the "clean air" cases for the modified wind tunnel curves.

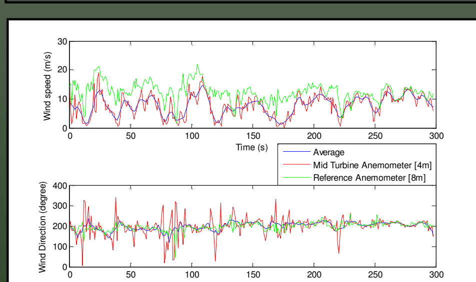

Figure 3: A five minute sample of wind direction and velocity and collected on the roof while testing of the VAWT.

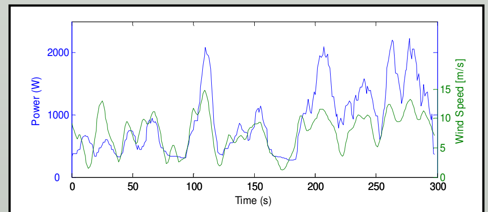

Figure 4: A comparison between the wind speed and power produced by the VAWT in a rooftop installation with the angular velocity held at 120 RPM.

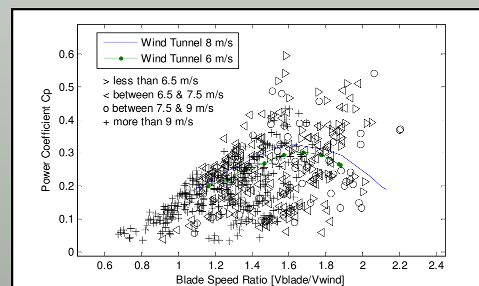

Figure 5: Unsteady transient rooftop results with a minimal wind velocity selection criteria imposed. The large scatter and very high Cp values are due to turbines response to the unsteady wind.

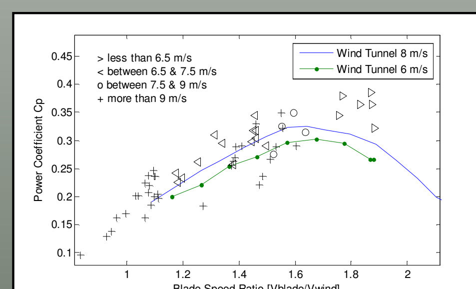

Figure 6: Performance curves from the wind tunnel compared to the selective rooftop results .

Conclusions

From this study, with a relatively short 10 second averaging duration, it is possible to extract the quasi steady state results from the rooftop data. These results agree well with the steady state wind tunnel experiments.

Future Work

The transient nature of the wind, and consequently the turbines, indicates that in order to develop a full performance analysis of the turbine it must be studied dynamically. Future work will focus on modelling the dynamic response of the turbine, while taking into account inertial effects and time delays for a peak power tracking controller.

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