Wind Turbine Load Measurements over a Steep 2D Hill

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Wind Turbine Load Measurements over a Steep 2D Hill

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Abstract: *An increasing number of wind farms are built over or close to complex terrain sites. These sites are associated with tough flow conditions and can affect wind turbine performance and life time. Wind tunnel test was carried out to investigate the effect of a steep two-dimensional hill on the performance of a horizontal axis wind turbine. Experiments were performed in the boundary layer wind tunnel to measure the load acted on a wind turbine at a number of locations over the hill. Moment acting on the wind turbine at the top of the hill was higher than moment acting on the turbine upstream of the hill.*

Keywords: Wind Tunnel Test, Wind Farms, Complex Terrains

1. INTRODUCTION

Wind turbines are grouped together in a wind farm to reduce the cost of energy production. However, several problems arise when a group of wind turbines are placed near to each other. The first row of wind turbines extracts kinetic energy from the wind, leading to a decrease in wind speed, therefore electricity production of the second row is reduced [1, 2]. The number of onshore wind turbines has significantly grown over the past few years [3]. More wind farms are built over or close to complex terrains such as hills, as possible sites with flat terrain are already developed. Complex terrain sites are associated with harsh flow conditions and can have a negative effect on wind turbine performance and life time, as these sites can induce large amounts of turbulence and high loads on wind turbine blades [4]. Therefore, wind farm terrain shape must be examined in addition to wind turbine wake effects during the process of wind farm layout optimization.

This paper examines the performance of a wind turbine located at different locations along a steep hill. The wind tunnel test was performed in the boundary layer wind tunnel of Kyushu University where a wind turbine was placed at different locations upstream and at the top of the hill in order to measure the load acting on the wind turbine.

2. METHOD

Measurements were performed in the boundary layer wind tunnel of Kyushu University (figure 1). The Boundary Layer Wind Tunnel is a closed circuit type and can be changed to an open circuit type when needed. The test section of the wind tunnel is 3.6 m (width) × 2 m (height) × 15 m (length). A uniform flow with turbulence intensity < 0.5 % can be achieved in the wind tunnel, and the maximum wind speed is 30 m / s [5].

Equation (1) represents the two-dimensional hill, where h is the hill height and equals to the diameter of the wind turbine rotor, L equals to h / 2S, S is the slope of the hill and equals to 0.45, Z-axis is the vertical direction, and X-axis is the streamwise direction. Figure 2 shows a schematic diagram of the 2D hill.

$$Z = h\, e^{\left[-0.5\left(\frac{X/L}{1.1774}\right)^{2}\right]} \quad (1)$$

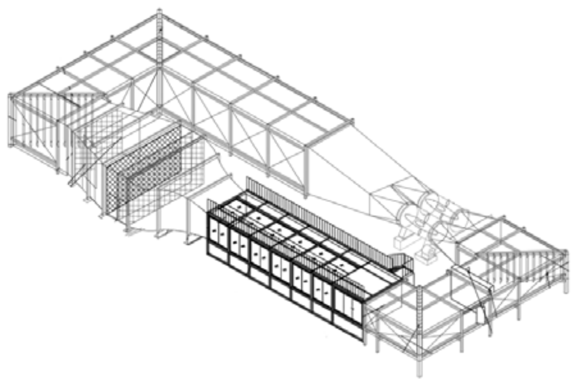

Fig. 1. Wind Tunnel of Kyushu University (Adapted from [5 and 6])

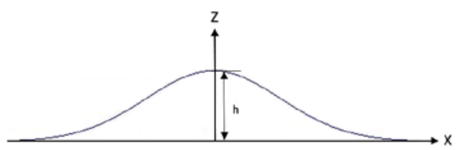

Fig. 2. Schematic diagram of the hill.

The inlet wind velocity was constant during all the measurements. The wind turbine was positioned at 6 locations over the hill along the streamwise direction as shown in figure 3. The forces acting on the wind turbine in X, Y, and Z directions and the moments about X, Y, and Z directions were examined using a 6 component load cell as shown in figure 3.

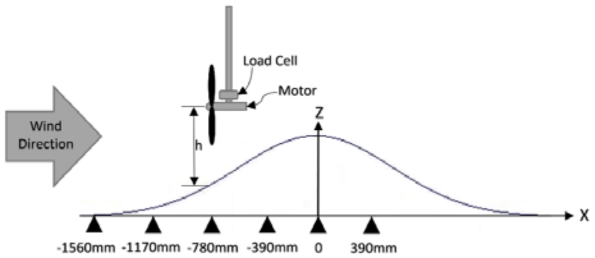

Fig. 3. Schematic diagram of the measurement setup.

3. RESULTS

Figure 4 shows the moment acting on the wind turbine at several locations over the hill at different Tip Speed Ratios (λ). Moment acting on turbine is highest at X = 0 and X = 390 mm, and lowest at X = -1560 mm. This is because wind speed at the top of the hill is higher than wind speed upstream of the hill.

The Power Coefficient (Cp) was calculated for the wind turbine at different Tip Speed Ratios (λ), as shown in figure 5. The wind turbine performance at the top of the hill (X=0) and X = 390 mm was better than that at X = -1560 mm. This is due to the higher hub wind speed at the top of the hill compared to the wind speed upstream of the hill. Figure 4 and 5 show the significant impact of the steep hill on wind turbine performance.

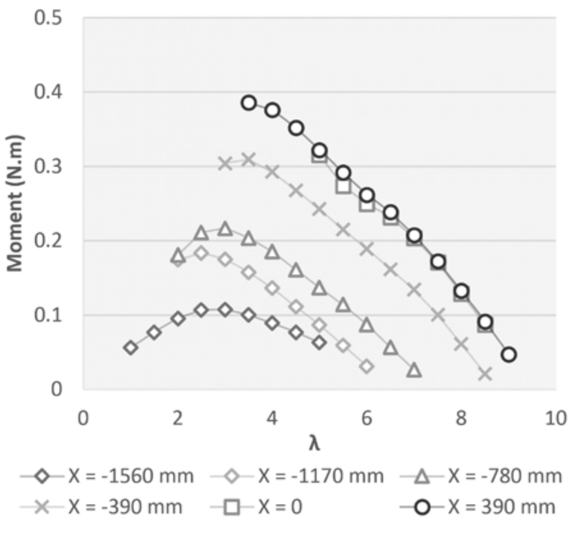

Fig. 4. Moment acting on wind turbine over hill.

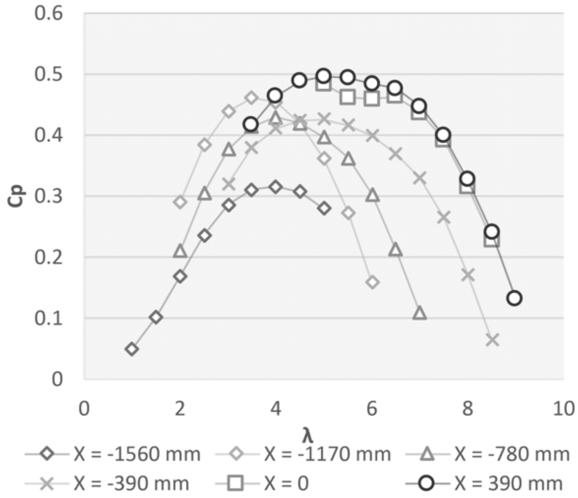

Fig. 5. Wind turbine power coefficient over hill.

4. CONCLUSIONS

This paper investigated the performance of a wind turbine located over different locations along a steep 2D hill. Measurements were performed in the boundary layer wind tunnel where a wind turbine was placed at 6 locations over the hill in order to measure the load acting on the wind turbine using a 6 component load cell. Moment acting on the wind turbine rotor was lowest upstream, and highest at the top of the hill. The Power Coefficient was calculated for the wind turbine at different tip speed ratios and the wind turbine performance at the top of the hill (X=0) and X = 390 mm was better than that upstream of the hill, due to the higher hub wind speed at the top of the hill. These results showed the effect of the steep hill on wind turbine performance.

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