A Validation of Digital Engineering's Wind Assessment Report

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1. EXECUTIVE SUMMARY

Digital Engineering has performed a validation of its wind assessment process. This document provides the details of this validation and presents the results.

In addition to the internal and customer validation work that has been performed, four of these sites were independently validated by Green Cat Renewables. Green Cat Renewables are technical advisors to some of the largest financial organisation involved in funding medium scale wind projects. They are also experienced users of wind data. For each of the four masts that were assessed on a blind test basis, the Digital Engineering process was 0.1 m/s away from the measured wind speed. The feedback was positive:

"The agreement is very good… in addition, the W90 applied by Digital Engineering to the above sites is of a similar level as we would expect to obtain via an MCP assessment using on site data."

Cameron Sutherland, Green Cat Renewables, March 2013

As a result of this validation exercise and previous validation work throughout the UK, Digital Engineering is confident that its wind prediction process is accurate. The industry standard measures of error in the wind speed estimate have been calculated and are presented below. The validation study has used physical masts ranging from 10m to 50m in height; therefore the accuracy stated is valid within that height range. It is expected that a similar level of error will be seen at higher hub heights but this has not been tested. The error between predicted and measured wind speeds was not found to be dependent on the complexity of the surrounding terrain and levels of nearby housing and vegetation.

Statistical quantity	Description	Value	Comments
$\bar{x}$	Process bias	-0.03	This value suggests that the method tends to under predict the real wind speed by 0.04 m/s
σ	Average error	0.36	The predicted wind speed was 0.36 m/s away from the real wind speed on average
W_{90} Reduction	Conservative estimate of the error	0.47	Subtracting 0.47 m/s from the calculated mean wind speed gives the wind speed that is 90% confident of being exceeded

Table 1: Summary and description of statistical quantities

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2. PROCESS OVERVIEW

Digital Engineering combines meso-scale wind data with computational fluid dynamics (CFD) modelling to provide an estimate of the wind resource at a site.

The first stage is to use a meso-scale model to obtain yearly average wind statistics. The wind speeds that are calculated by meso-scale models are most accurate at hub heights higher than 100m. The meso-scale models perform well at these heights and have served the large wind industry well for many years. At lower hub heights the meso-scale models perform less well as the effects of local topography, buildings and trees come into play. The meso-scale models are unable to include these features and significant inaccuracies can be introduced. This causes an issue, particularly for medium scale wind turbines that tend to have hub heights that are much closer to the ground. A solution to this problem is to use a computational fluid dynamics (CFD) code to account for these effects. These codes model airflow extremely accurately and are in common use in the aerospace industry and Formula 1.

The first stage of the CFD process is to create a three-dimensional model of the local area. All the terrain within 5 km of the proposed location is accounted for. 3D models of all the buildings, trees and hedges within 1km of the turbine are then placed on top of this terrain. The CFD models airflow up to 1km in the atmosphere. As the CFD code is unable to predict the meso-scale wind speeds in the atmosphere, the meso-scale data is required at this stage. The CFD code is run until the wind speed and direction matches those predicted by the meso-scale model at 100m. The CFD code is then stopped and the wind speed at the turbine’s location and hub height is extracted from the CFD results. This process is repeated for each wind speed and direction in the meso-scale wind rose. The results are averaged to give a yearly average wind speed.

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3. VALIDATION STUDIES TO DATE

3.1. SOURCES OF DATA

In order to prove the accuracy of Digital Engineering's combined meso-scale and CFD process, a validation study was performed. A total of 35 sites were used, covering a range of hub heights and measuring periods. The locations can be seen below in Figure 1 and the hub heights, site characteristics and measurement periods can be summarised in Table 2.

Figure 1: Locations of measuring stations

Number of sites	Hub height (m)	Change in elevation within 5km (m)	Percentage of total area within 1km covered by vegetation (%)	Percentage of total area within 1km covered by buildings (%)	Combined measurement period (years)
35	10 – 50	5 – 325	0% – 55%	0% – 10%	225

Table 2: Summary of hub height, site characteristics and measuring periods of the measuring stations

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3.2. VALIDATION CRITERIA

In order to test the accuracy of the computed data, the industry requires the computation of three statistical quantities which reflect the quality of the modelling. In order to do this, the site error is defined as follows. The computed wind speed for the n^{th} site (C_N) is subtracted from the measured wind speed for the n^{th} site (M_N) to give an error for the n^{th} site, E_N.

$$E_N = C_N - M_N$$

With this in mind, the statistical quantities that are calculated are

- The mean error - $\bar{x}$: This is the average difference between the computed wind speed and the measured wind speed. It is also known as the bias. If $\bar{x}$ is greater than 0, it shows a tendency for over prediction of wind speed and if it is less than 0, it shows a tendency for under prediction of wind speed. For a robust process, $\bar{x}$ should be close to zero. It is defined as follows.

$$\bar{x} = \frac{1}{N}\sum(E_N)$$

- The standard deviation - σ : This is the average difference between the measured wind speed and the predicted wind speed, regardless of whether of the measured wind speed was higher or lower than the predicted wind speed. This will always be greater than zero but the closer it is to zero, the better the modelling process.

$$\sigma = \frac{1}{N-1}\sum\left[\sqrt{\left(E_N - \bar{x}\right)^2}\right]$$

- The 90^{th} percentile of the errors – W_{90} Reduction: This is the 90^{th} percentile of the errors assuming a normal distribution. It is a commonly used quantity when conducting financial analysis of a site. Subtracting this quantity from the calculated mean wind speed gives the wind speed that the method is 90% confident of exceeding. It is calculated as 1.28 times the standard deviation, σ.

3.3. WEIGHTING FACTOR

When calculating the error statistics, a standard weighting function was used to account for the different lengths of measuring periods in the data set. All sites with over 12 months of data were given the same weight; sites with less data were given a lower weight that was linearly related to the length of data set.

The weighting function of the n^{th} site, w_N, was defined as follows in terms of the length of measured data available in months, t_n.

$$for\ t_N < 12: \qquad w_N = \left(\frac{t_N}{12}\right)$$

$$for\ t_N \geq 12: \qquad w_N = 1$$

3.4. RESULTS

The results of the validation exercise are summarised in Table 3 below.

Statistical quantity	Value (m/s)
$\bar{x}$	-0.03
σ	0.36
W_{90} Reduction	0.47

Table 3: Summary of statistical quantities for the errors between predicted and measured wind speeds

The data from the validation exercise can be shown graphically in Figure 2. This shows good agreement between the predicted and measured wind speeds at the sites.

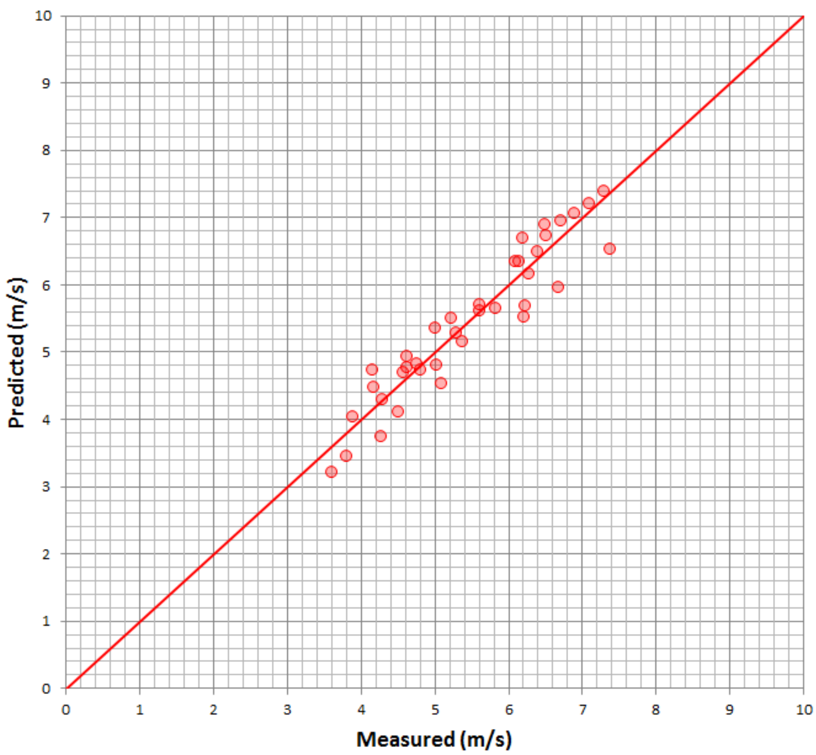

Figure 2: Graph of predicted wind speed versus measured wind speed

4. INDEPENDENT VALIDATION

In addition to the internal and customer validation work that has been performed, four of the thirty-five sites mentioned above were independently validated by Green Cat Renewables. Green Cat Renewables are technical advisors to some of the largest financial organisation involved in funding medium scale wind projects. They are also experienced users of wind data.

This validation was performed on a blind test basis. As such Green Cat Renewables supplied the co-ordinates and a hub height for four of their met masts along with the start and end dates of the wind measurement campaigns. The wind speed was known to them at this point but unknown to Digital Engineering. The aim of the study was to predict the wind speed observed at the site during the measurement campaign. Details of the four sites are as follows.

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Area in Scotland	Hub height (m)	Length of measurement campaign (months)
Aberdeenshire	30	21
Borders	40	11
North Lanarkshire	50	12
Perthshire	50	15

Table 4: Details of the independent verification test sites.

Digital Engineering produced wind resource reports for each of the four sites and supplied them to Green Cat Renewables. Green Cat compared our reports with the data from the masts and supplied the results.

The results were in excellent agreement with the masts. They are as follows.

Area in Scotland	Measured Wind Speed (m/s)	Predicted Wind Speed (m/s)	Difference (m/s)
Aberdeenshire	7.1	7.2	0.1
Borders	7.3	7.4	0.1
North Lanarkshire	6.4	6.5	0.1
Perthshire	5.6	5.7	0.1

Table 5: Details of the independent verification test sites.

5. CONCLUSION

Digital Engineering has carried out a validation exercise of its wind assessment process. Simulated data for a total of 35 sites of varied complexity has been compared against 225 years of measured data. The measured wind speeds from heights ranging from 10m to 50m above ground level have been compared to the predicted values and table of errors has been compiled.

A statistical analysis of the errors has been performed and three parameters have been used to quantify the certainty of the wind speed estimates: the bias, the standard deviation and the 90th percentile of the error. From such analysis, it has been concluded that the wind prediction process is marginally conservative with a bias of -0.03m/s and the average error is 0.36 m/s. The results also indicate that subtracting 0.47 m/s from the calculated mean wind speed gives the wind speed that the method is 90% confident of exceeding.

Furthermore, it was observed that the measured errors were not correlated with the local characteristics of the sites such as the terrain elevation change and the total area covered by vegetation and/or building features. This is an indication that the certainty in the prediction process is independent of the complexity of the site.

The analysis of errors presented in this report suggests that the validated wind prediction process is one of the most accurate approaches currently available in the market.

As a result of this exercise Digital Engineering has a high level of confidence that its wind prediction process is accurate in the UK, within the uncertainty limits quoted. Validation studies are on-going at Digital Engineering as part of a continuous improvement policy and the uncertainty limits may change. The current uncertainty limits should always be checked before the data is used.

6. REFERENCES

[1] International Standard IEC61400-1: “Wind Turbines – Part 1”, Third Edition, 2005