Vertical Wind Shear Profiles in Downburst Events and the Insufficiency of Wind Turbine Design Codes

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1 INTRODUCTION

The extreme wind speed model published in IEC61400-1 (2005) Wind Turbine – Part 1: Design Requirements [1] have provision for predicting wind speeds based on an assumed alpha value of 0.11, based on a power law vertical shear profile.

Based on data from sixteen Australasian wind monitoring sites, this model for shear in extreme wind speeds has been shown to be insufficient and the data collected raises serious doubts as to the appropriateness of fitting a power law profile. A large proportion of the extreme wind events captured appear to be downburst events.

Wind monitoring was conducted at heights ranging from 10 m to 80 m AGL. The monitoring was conducted for the purpose of wind farm development; therefore, the site details must remain anonymous.

2 THE EXTREME WIND MODEL

Wind turbines generators are classified based on their ability to withstand extreme winds and turbulence. Extreme wind analysis is based on extreme-value statistical methods including the Gumbel analysis. As a result of this, long records, ideally 20 years, are required to give the analysis statistical veracity [2, 3]. Hub height long term records are not generally available; as a result, various techniques have been developed to work around this, including correlation with other wind speed data.

Extreme wind analysis thus often relies on below hub height measurements which are used to predict wind speeds at hub height. Prediction of wind speed from a lower height to a higher height is a common practice in wind analysis. This process generally utilises a power law relationship of the following form:

$$V(z) = V_{hub}(z / z_{hub})^{\alpha}$$

V(z) is the wind speed at height z,

V_{hub} is the velocity at hub height,

z_{hub} is the hub height,

α is a constant, representing the power law exponent, as defined in IEC61400-1 (2005) Wind Turbine – Part 1: Design Requirements [1].

This relationship is found to hold within acceptable tolerances where z is a minimum of three-quarters of z_{hub} [4]. The Extreme Wind-speed Model (EWM) defined in IEC61400-1 (2005) Wind Turbine – Part 1: Design Requirements consists of the power law relationship with a power law exponent α set at 0.11. The wind speeds in the context of the EWM are 3 s gust wind speeds. [1]

One of the key parameters for selecting a wind turbine generator for a site is how its design class matches up with the extreme wind regime on-site. Classes of turbines, based on survival wind speeds are listed in Table 1. V_{ref} is the 10-minute averaged 50 year return period wind speed, while V_{e50} is the 3 s gust wind speed with 50 year return period.

Table 1: Wind Turbine Classes as specified by IEC61400-1 (2005) Wind Turbine – Part 1: Design Requirements [1]

Wind Turbine Class	I	II	III
V_{ref} [m/s]	50	42.5	37.5
V_{e50} [m/s]	70	59.5	52.5

While wind turbine manufacturers and designers do not necessarily specifically design to this standard, their turbines are nonetheless accredited based on this standard, and matched to site wind conditions based on that accreditation.

3 WIND MONITORING CAMPAIGNS

The analysis is based on data that Hydro Tasmania Consulting has accumulated over a twenty year period. The bulk of the sixteen sites are based in south-eastern Australia, with one site in Western Australia and two sites in New Zealand. Seven of the sites are considered to be coastal sites. The remaining nine sites are considered to be inland sites.

Further sites across Australia, New Zealand, China, India and South Africa were examined, but maximum gust speeds did not exceed 40 m/s, hence were not included in the analysis.

The height of measurements is presented in Table 2. As can be seen, twelve of sixteen sites have typical hub height instruments and there is good representation of coastal and inland sites.

Time series for wind events with peak wind speeds greater than 40 m/s were extracted from the database.

Table 2: Site list, anemometry heights, locations and events greater than 40 m/s.

Site	10m	16.5m	20m	30m	45m	50m	70m	80m	Location	Events
1				X		X	X		Inland	1
2				X		X	X		Coastal	7
3	X			X		X			Coastal	4
4	X			X		X			Inland	3
5		X		X					Coastal	7
6				X		X	X		Coastal	8
7				X			X		Coastal	3
8				X		X	X	X	Inland	1
9				X		X	X	X	Inland	1
10				X		X		X	Inland	2
11				X		X		X	Inland	2
12				X		X		X	Inland	2
13				X		X		X	Coastal	2
14				X		X			Inland	1
15				X		X		X	Inland	4
16				X	X		X		Coastal	12

The anemometry at all but three of the sites was Vaisala cup anemometers (WAA151) and Vaisala vane (WAV151). The remaining sites used Risøe anemometers (P2546) and Vector wind vanes (W200P). These were all mounted on triangular lattice masts.

Thirteen of the sixteen arrangements do not conform to best practice installations based on IEC61400-12-1 Appendix G as the vanes and anemometers were mounted side by side and the boom arms were of rectangular cross-section rather than streamlined for minimal flow interference. The remaining three sites conform to current international best practice wind monitoring [5].

The monitoring conducted using the Vaisala instrumentation recorded 150 s means and 2 s gusts. The remaining sites recorded 600 s means and 3 s gusts.

4 CHARACTERISING EVENTS AS DOWNBURSTS

Thunderstorm events are responsible for downburst events when warm moist air from the thunderstorm updraft can no longer be sustained [6]. The air cools and the density increases and cool air rushes downwards and spreads radially as it hits the ground. As such, downbursts are characterised by the following:

- Short lived event – lasting between 5 minutes and 30 minutes;
- Temperature drop – 1.5°C or more across the duration of the downburst;
- Increase in wind speed at more than one height;
- Wind speed differential greater than 10 m/s [7].

Data series have been examined according to these criteria and an assessment has been made as to whether a downburst event has occurred.

Thunderstorm downbursts are also renowned for their distinctive vertical shear profiles with the maximum speeds, also known as the nose of the profile, typically between 50 m and 100 m AGL. Downbursts are sometimes, but not always associated with changes in wind direction.

5 SUMMARY OF PROFILES AND FURTHER WORK

With a significant number of extreme wind events attributable to downburst events, as seen in Table 3, it can be confirmed that in southern Australia, downbursts are responsible for a significant percentage of extreme wind events.

Table 3: Distribution of Downburst Events

Site	Events	Downburst Events		Site	Events	Downburst Events
1	1	0		9	1	1
2	7	6		10	2	1
3	4	3		11	2	0
4	3	1		12	2	0
5	7	2		13	2	2
6	8	5		14	1	0
7	3	0		15	4	1
8	1	1		16	12	9
				TOTAL	60	32

This preliminary analysis of the frequency of extreme wind events, and subsequently the frequency of downbursts within that dataset, demonstrates that extreme wind models, in particularly that provided in [1] should account for such wind events. However, if the vertical wind shear profiles obtained are consistent with the EWM, there is no need for further refinement of the EWM.

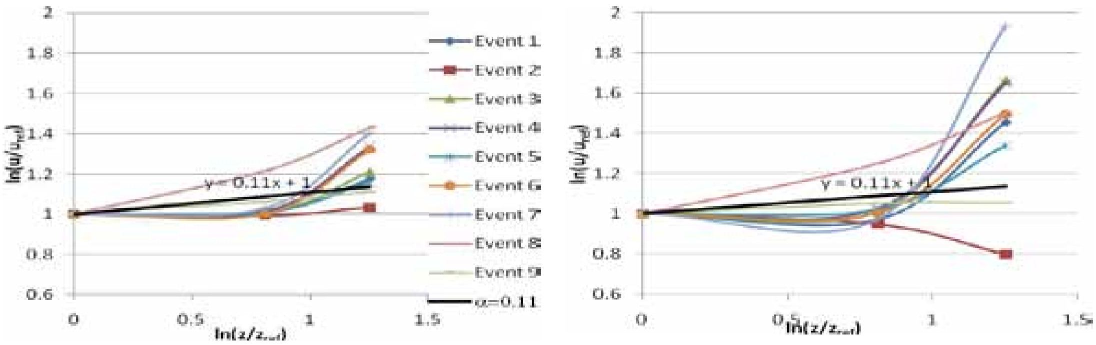

Fig. 1: (left)Natural logs of normalised 150 s mean wind speeds against natural logs of normalised heights for downburst events from site 16. (right) Natural logs of normalised 2 s gust wind speeds against natural logs of normalised height for downburst events from site 16. Legend is common for both charts.

Fig. 1 is a plot of the natural logs of normalised wind speeds and heights from site 16. Results from Fig. 1 are typical of results from the other sites. The other results have been omitted for clarity and brevity.

In a typical power law profile, including the profile from the aforementioned EWM, the points should be approximately linear with the gradient representing the power law exponent, α. The black line in each figure represents the EWM. Whilst data from only one site is shown in the figures, they still emphasise the insufficiency of the EWM, both in type (power law profile) and in magnitude (exponent insufficiently conservative). The first point is clear from the fact that only Events 2, 8 and 9 are remotely linear, and indeed, only Events 2 and 9 at site 16 fit with the prescribed shear exponent. Furthermore, the right hand graph, representing 2 s wind gusts, demonstrates a far more significant divergence from the EWM than the 150 s mean profiles.

Referencing this data from the 20 m level parallels practice where long term records are obtained from, for example the Bureau of Meteorology, typically at a height of 10 m AGL, upon which a Gumbel analysis or similar is completed to determine the 50-year return wind speeds. The hub height V_{e50} are merely scaled up according to the EWM. The findings of this research are that the EWM is simply an insufficient tool with which to scale up wind speeds.

Further work to be completed is investigating the impact of terrain on the results. It is expected that terrain plays a significant part in determining the shape and magnitude of the vertical wind shear profiles; however, this needs to be quantified. The Design Requirement standard [1] makes no consideration of terrain effects, except that the EWM should not to be used for the assessment of off-shore wind farms.

6 REFERENCES

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