FULCRUM3D Shadow Flicker Assessment

Lord Howe Island

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Author: Daniel Gilbert BE (Hons) UNSW

Fulcrum3D Pty Ltd

ABN 73 151 086 510

Level 11, 75 Miller St

NORTH SYDNEY, NSW 2060

Tel: +61 02 8456 7400
info@fulcrum3d.com
www.fulcrum3d.com

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Introduction

Due to their height, wind turbines can cast shadows on the areas around them. Coupled with this, the moving blades create moving shadows. When viewed from a stationary position, when the turbine is between the viewer and the sun, the moving shadows appear as a flicker giving rise to the phenomenon of 'shadow flicker'. This is similar to the strobe effect often experienced when driving through scattered trees on a rural highway.

For a particular position, shadow flicker will only occur during periods when the sun's rays pass directly through the swept area of the turbine blades to the viewpoint. There are, however, a number of other factors influencing the effect and duration of shadow flicker including:

- position of the sun in relation to the turbine;
- time of year (season) and time of day;
- turbine height and rotor diameter;
- viewer's distance from turbine;
- topography of the area;
- vegetation cover;
- weather patterns, number of cloudy days per year; and
- airborne particles, haze.

The effect of 'chopping the light' attenuates with distance and is not considered by modellers of shadow flicker to be noticed beyond 500 – 1,000 m from a turbine (Osten and Pahlke, 1998). In addition, the South Australian Planning Bulletin suggests that shadow flicker is insignificant once a separation of 500 m between the turbine and house is exceeded.

The Victorian Planning Guidelines limit the duration of shadow flicker to a maximum of 30 hours per year (SEAV, 2003). In NSW there are currently no legislated guidelines on which to assess shadow flicker generated by wind turbines, although consideration has also been made in this assessment to the *Draft* NSW Wind Farm Planning guidelines, which require that:

> *"The impact of 'shadow flicker' from wind turbines on neighbour's houses within 2km of a proposed wind turbine should be assessed. The shadow flicker experienced at any dwelling should not exceed 30 hours per year as a result of the operation of the wind farm. Specialist modelling software should be used to model shadow flicker impacts prior to finalisation of the turbine layout"*

This assessment has assessed the generally accepted maximum limit of shadow flicker out to 1 km and 2 km as required in the draft NSW Wind Farm development guidelines.

Background

Shadow flicker is an amenity issue rather than a health risk. Given it is a daytime event; it does not interrupt sleep patterns. However, two issues have been raised as potential health concerns in relation to shadow flicker which can be mitigated by turbine selection and wind farm project design. Details are below:

Flicker vertigo

Flicker vertigo is an imbalance in brain cell activity caused by exposure to low frequency flickering or flashing of a light or sunlight seen through a rotating propeller (Rash, 2004). It can result in nausea, dizziness, headache, panic, confusion and – in rare cases – loss of consciousness. Flicker vertigo is usually associated with a light flashing sequence, or flicker frequency, of between approximately 4 hertz (cycles per second) and 20 Hz (NASA, 2001; Rash, 2004).

Photosensitive Epilepsy

Flicker from turbines that interrupt or reflect sunlight at frequencies greater than 3 Hz poses a potential risk of inducing photosensitive seizures. The risk is maintained over considerable distances from the light source. The flicker frequency is dependent upon the rotational speed of the wind turbine. It is therefore important to keep rotation speeds below 3 hertz. The layout of wind farms should ensure that shadows cast by one turbine upon another should not be readily visible to the general public or fall upon nearby homes (Harding et al., 2008).

An assessment of these two health concerns is provided in the Results section of this document.

Assessment

A detailed analysis of the potential for shadow flicker & blade glint to affect dwellings has been carried out by Fulcrum3D. Modelling of the shadow flicker was conducted using specialist industry software, assessing the largest turbine (maximum tip height) proposed for the project to represent the worst case impact scenario. The maximum number of annual hours at each of the nearby houses and buildings where shadow flicker may be experienced was calculated using this model. Guidelines and legislation for Shadow Flicker has been taken from NSW, Victoria, South Australia and Worldwide where appropriate, as discussed below.

Turbine Model

There are two turbine types that have been proposed. These are the:

- Vergnet GEV MP C
    - 200kW
    - 2 Blades
    - 55m Hub Heights
    - 15m Blade Length
    - 71m Tip Height
- Xant 21
    - 100kW
    - 3 Blades
    - 31.8m Hub Heights
    - 10.5m Blade Length
    - 43m Tip Height

As the Vergnet GEV MP C is the larger turbine with a larger rotor diameter and higher tip height, this assessment is performed using this turbine as the worst case impact scenario.

Model Details

The number of annual hours of shadow flicker at a given location can be calculated using geometrical models incorporating data such as the sun path, the topographic variation and wind turbine details such as rotor diameter and hub height. In such models, Shadow flicker calculated is overestimated due to several reasons.

- The wind turbine rotor is modelled as a disc and assumed to be in the worst case (i.e. perpendicular) to sun-turbine vector at all times. The probability of wind turbines consistently yawing to the ‘worst case’ scenario where the wind turbine is facing into or away from the sun- wind turbine vector is less than 1 (i.e. less than 100% of the time).
    - If required, this can be predicted using on site wind rose data. This would reduce the shadow flicker impact when the turbines are not facing into or away from the sun.
- Modelling the sun as a point light source rather than a small disc increases predicted shadow flicker for the following reasons.
    - Situations arise where the light rays from different portions of the sun disc superimpose around a shadow resulting in light intensity variations less than human perception.

- When the sun is positioned directly behind the wind turbine hub, there is no variation in light intensity at the receiver location and therefore no shadow flicker. However, when the sun is modelled as a point source, shadow flicker still arises.

- The occurrence of cloud cover has the potential to significantly reduce the number of hours of shadow flicker
- The amount of aerosols in the atmosphere has the ability to influence shadows cast due to the following reasons:
  - The distance from a wind turbine that a shadow can be cast is dependent on the degree to which direct sunlight is diffused, which is in turn dependent on the amount of dispersants (humidity, smoke and other aerosols) in the path between the light source (sun) and the receiver.
  - The quantity of aerosols in the air is known to vary with time and it has the potential to vary the air density, thereby affecting the refraction of light. This in turn affects the intensity of direct light to cause shadows.
- The blades are of non-uniform width with the thickest viewable blade width (maximum chord) generally occurring closer to the hub and the thinnest being located at the tip of the blade. As outlined above, the direct sunlight is diffused resulting in a maximum distance from the wind turbine that a shadow can be cast. This maximum distance is dependent on the human threshold which variation in light intensity can be perceived. When the blade tip causes shadow, the diffusion of direct sunlight means that the light variation threshold occurs closer to the wind turbine than when a shadow is caused by the maximum chord. That is, the maximum shadow length cast by the blade tip is less than by the maximum chord.
- The presence of vegetation shields incidences of shadow flicker.
- Periods where the wind turbine is not in operation due to low winds, high winds or operational and maintenance reasons.

Therefore, the modelling conducted here represents a very conservative scenario and is intended to overestimate the actual annual hours of shadow flicker experienced at a location.

Impact Distance

The South Australian Planning Bulletin suggests that shadow flicker is insignificant once a separation of 500m between the turbine and house is exceeded (Planning SA, 2002). The UK wind industry and UK government recommends 10 rotor diameters as the maximum shadow length from a wind turbine that will cause annoyance due to shadow flicker, this equates to 300m for the proposed 30m blade diameter (ODPMUK, 2004). The EPHC Draft National Wind Farm Development Guidelines suggest a distance equivalent to 265 maximum blade chords as an appropriate limit which corresponds to 530m for a 2m maximum blade chord as found on the proposed turbines (EPHC, 2010). This issue is discussed in the EPHC Draft National Wind Farm Guidelines which states:

> *Shadow flicker can theoretically extend many kilometres from a wind turbine. However the intensity of the shadows decreases with distance. While acknowledging that different individuals have different levels of sensitivity and may be annoyed by different levels of shadow intensity, these guidelines limit assessment to moderate levels of intensity (i.e., well above the minimum theoretically detectable threshold) commensurate with the nature of the impact and the environment in which it is experienced.*

The Draft NSW Wind Farm Development Guidelines suggest that shadow flicker should be assessed out to 2 km from the turbines.

As a conservative measure a maximum shadow distance of 1000m is used as an input to this assessment model for the expected case. An assessment out to 2 km has also been conducted to show the absolute theoretical worst case scenario, despite this distance from the turbines to the receiver to be much further than the distance that shadow flicker can be detected.

Shadow Flicker Duration

To carry out the shadow flicker assessment the Draft NSW Wind Farm Development Guidelines, Victorian Planning Guidelines and the South Australian Planning Bulletin were used to determine the inputs to the model. They state a maximum duration of shadow flicker at any residence of 30 hours per year.

WEATHER CONDITIONS & VEGETATION SCREENING AT LORD HOWE ISLAND

When the actual weather conditions of the Lord Howe Is site are taken into consideration, the number of hours of shadow flicker should be reduced. The consideration in this respect is the weather patterns and particularly the number of cloudy days experienced that would result in no shadow flicker.

Based on 17 years of data (collected between 1989 and 2010) of daily weather observations on Lord Howe Island (Lord Howe Island, Bureau of Meteorology), the average number of cloudy days experienced is 106.5 days/year. The average number of clear days experienced is 67.8/year. The remaining days of the year experience a mixture of both cloud cover and clear sky. These are based on observations at 9am and 3pm each day. Accordingly based on 106.5 days/year of cloudy days the number of shadow flicker hours should be reduced by 29.1%.

Further reductions for vegetation screening should be considered and applied where appropriate on a case by case basis.

Results

The shadow flicker modelling has calculated the number of annual hours at each of the nearby houses & buildings and the results are presented below in Table 1. All of the 215 buildings within 1km of the turbines, including all 110 residential buildings individually have a total number of shadow flicker hours as less than 30 hours per year.

Table 1 – Shadow Flicker Assessment of Buildings within 1km of Turbines

Type of Building	*Annual Hours of Shadow Flicker*		
	0	*0 – 30*	*> 30*
Residential	78	32	0
To be assessed	24	12	0
Commercial	0	11	0
Community	0	3	0
Shed	35	20	0
Total	**137**	**78**	**0**

The results show compliance with the Draft NSW Wind Farm guidelines recommendation and the Victorian Guidelines of 30 hours/year at all residences within 1 km.

The shadow flicker modelling has then been recalculated for a distance up to 2 km from the turbines, to show a worst case scenario. This is shown below in Table 2. The results of the 2 km shadow flicker are also shown on a map at the end of this section in Figure 1.

Table 2 - Shadow Flicker Assessment of Buildings within 2km of Turbines

Type of Building	*Annual Hours of Shadow Flicker*		
	0	*0 – 30*	*> 30*
Residential	174	38	0
To be assessed	54	22	0
Commercial	2	16	0
Community	0	3	0
Shed	86	24	0
Total	**314**	**105**	**0**

The results show compliance with the Draft NSW Wind Farm guidelines recommendation and the Victorian Guidelines of 30 hours/year at all residences within 1 km.

A list of named locations as important points of interest was provided as part of the inputs to the assessment. The individual result of this assessment for each named location is provided in Table 3. This includes the highest impact to an individual building, 19 hours of shadow flicker per year to the Pinetrees Laundry. Additionally a reduction of the theoretical maximum number of hours can be assumed based on the long term observation of cloudy days as shown in the third column of Table 3.

Table 3 - Result of shadow flicker assessment to named locations & points of interest

Named Locations & Points of Interest	Annual Hours of Shadow Flicker (sorted descending)	Annual Hours of Shadow Flicker Reduced Due to Cloud Cover
Pinetrees Laundry	19	13
Pinetrees Accommodation Wing	12	9
Bruce & Kerry McFadyen Residence	11	8
The Barn Residence	10	7
Pinetrees Staff Accommodation	10	7
Bowling club	5	4
Board Offices & Depot	5	4
Central School	4	3
Rabbit Island	1	1
Jim & Rachael McFadyen Driveway	0	0
Palmhaven Residential	0	0
Krick Residence	0	0
Powerhouse Building	0	0
Air Services Australia Tower	0	0
Transit Hill	0	0
Intermediate Hill	0	0
Mt Gower View Point	0	0
Catalina Crash Site View Point	0	0
Malabar View Point	0	0
Kims Lookout View Point	0	0
Airport Runway	0	0

The results show compliance with the Draft NSW Wind Farm guidelines and the Victorian Guidelines of 30 hours/year at all named locations and points of interest.

Figure 1 - Lord Howe Island shadow flicker map up to 2 km from turbines

HEALTH EFFECTS FROM SHADOW FLICKER

Flicker frequency of rotating propellers, including wind farm rotors, is derived by multiplying the hub rotation frequency by the number of blades. Based on the rotation speed of the 2 bladed wind turbines proposed (maximum RPM of 46Hz) for the project, the maximum shadow flicker frequency would be approximately 1 - 1.5 cycles per second (1 Hz), well outside the frequency range associated of 3-30 Hz with flicker vertigo or photosensitive epilepsy. The project is therefore unlikely to represent a health risk to local residents in relation to flicker vertigo or photosensitive epilepsy.

This sentiment is also reflected in a recent public statement by the National Health and Medical Research Council titled ‘Wind Turbines and Health’ which has stated that the evidence on shadow flicker does not support a health concern (NHMRC, 2010).

BLADE GLINT

Blade glint occurs when sunlight is reflected off turbine blades. The concern is that this may affect some motorists or cause annoyance at dwellings.

Turbine manufacturers have acknowledged the possibility of blade glint and use a low reflectivity gel finish to reduce any reflectivity. The turbines proposed for this project would be finished in a matte, non-reflective finish to ensure blade glint impacts are reduced as far as possible. In addition, the moving blades are typically convex in nature which act to disperse the light rather than reflect which acts to further reduce the change of blade glint. These measures are considered sufficient to mitigate the risk of blade glint.

Conclusion

Shadow flicker can be present at wind farm sites. As described above, it is considered an amenity concern rather than a health risk since the frequency of the flicker from the proposed wind farms is low than the threshold for flicker vertigo and photosensitive epilepsy.

An industry standard shadow flicker model has been implemented using turbine and receiver locations as well as a number of conservative assumptions. It is therefore assumed that the model is likely to significantly over predict actual shadow flicker.

The worst case predicted shadow flicker at each dwelling within 1 km of the proposed wind turbines has been assessed and no residential building exceeds the accepted limit of 30 hours per year, as shown in Table 1. Additionally an assessment has been made out to 2km from the wind turbines as a worst case scenario and has found that no residential building exceeds the accepted limit of 30 hours per year, as shown in Table 2. This is also shown graphically in Figure 1.

Standard mitigation measures including matt turbine finishes and the convex nature of the moving blades is deemed sufficient to mitigate blade glint.

Mitigation Measures

This assessment has found that the shadow flicker will not have a large enough impact to require mitigation measures. However, there are a number of mitigation measures that could be implemented if required once the wind farm is operational:

- if shadow flicker is found to be a nuisance at a particular residence at a known location a physical screen can be placed between the location and the wind turbines. Additional trees or other vegetation can be used to accomplish this.
- appropriate mitigation measures will be negotiated and implemented, where necessary, including potential limiting hours of operation on selected turbines or pre-programming the control system of individual wind turbines to automatically shut down while these conditions are present.
- shadow flicker effects on motorists can be monitored following commissioning and any remedial measures to address concerns would be developed in consultation with the Lord Howe Island Board, RMS and the Department of Planning.

Fulcrum3D Pty Limited

ABN 73 151 086 510

Level 11, 75 Miller St

North Sydney NSW 2060

Tel: +61 2 8456 7400

Email: info@fulcrum3d.com

Web: www.fulcrum3d.com