SHADOW FLICKER AND BLADE GLINT ASSESSMENT FOR THE PROPOSED CAPITAL II WIND FARM

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1 EXECUTIVE SUMMARY

Garrad Hassan Pacific Pty Ltd (GH) has been commissioned by Moir Landscape Architecture (MLA) on behalf of Infigen Energy Australia Pty Ltd (Infigen) to independently assess the shadow flicker in the vicinity of the proposed Capital II Wind Farm. The results of the work are reported here. This document has been prepared pursuant to the GH proposal P1078/PP/01 Issue A, dated 20 September 2010, and is subject to the terms and conditions contained therein.

This document assesses the potential impact of shadow flicker and blade glint from the wind farm.

Shadow flicker involves the modulation of light levels resulting from the periodic passage of a rotating wind turbine blade between the sun and a viewer. The duration of shadow flicker experienced at a specific location can be determined using a purely geometric analysis which takes into account the relative positions of the sun throughout the year, the wind turbines at the site, and the viewer. This method has been used to determine the shadow flicker duration at sensitive locations neighbouring the proposed Capital II wind farm.

GH notes that this analysis method tends to be conservative and typically results in over-estimation of the number of hours of shadow flicker experienced at a dwelling [1]. An assessment of the probable degree of conservatism associated with the analysis has not been conducted.

Infigen has supplied a turbine layout for the wind farm consisting of 53 turbines with a hub height of 100 m and a rotor diameter of 114 m [2]. These wind turbine dimensions are considered to be a ‘worse case’ scenario.

In NSW there are no specific Guidelines on how to assess shadow flicker generated by wind turbines. However, a number of assessments have applied the Victorian Planning Guidelines [3] which recommend a shadow flicker limit of 30 hours per year in the area immediately surrounding a dwelling.

In addition, there are Draft National Wind Farm Development Guidelines [4] which recommend a limit on the theoretical shadow flicker duration of 30 hours per year, and a limit on the actual shadow flicker duration of 10 hours per year. The Draft National Guidelines also recommend a modelling methodology.

An estimate of shadow flicker duration has been undertaken by assessing theoretical shadow flicker assuming a worst case scenario. Turbine orientation and cloud cover which is expected to reduce the shadow flicker duration below the theoretical values has not been assessed.

Blade glint involves the reflection of light from a turbine blade, and can be seen by an observer as a periodic flash of light coming from the wind turbine. Blade glint is not generally a problem for modern turbines provided non-reflective coatings are used for the surface of the blades.

2 DESCRIPTION OF THE PROPOSED WIND FARM SITE

2.1 Site description

The Capital II site is located approximately 18 km north of Bungendore, in New South Wales.

The town of Bungendore is situated some 40 km northeast of Canberra. The proposed wind farm is located along the shoreline of Lake George and series of undulating hills. The elevation of the site varies between approximately 680 m and 705 m.

The vegetation in the region is predominantly open farmland.

2.2 House locations

A list of co-ordinates of dwellings to be considered as shadow flicker receptors have not been provided for the purpose of the shadow flicker assessment. Hence, this assessment identifies areas where there are potential shadow flicker issues.

2.3 Proposed Wind Farm layout

Infigen has supplied the proposed layout of the Capital II wind farm, which is composed of 53 wind turbines. A hub height of 100 m and a rotor diameter of 114 m were considered for the shadow flicker modelling of the proposed Capital II wind farm.

A list of co-ordinates of proposed turbine locations has been provided by Infigen [2]. These co-ordinates are shown in Table 1.

A hub height of 80 m and a rotor diameter of 88 m were considered for the shadow flicker modelling of the existing 67 Suzlon S88 wind turbines comprising the Capital I wind farm.

3 PLANNING GUIDELINES

In NSW there are no specific Guidelines on how to assess shadow flicker generated by wind turbines. However, a number of assessments have applied the Victorian Planning Guidelines which currently state;

"The shadow flicker experienced immediately surrounding the area of a dwelling (garden fenced area) must not exceed 30 hours per year as a result of the operation of the wind energy facility".

In addition, the EPHC Draft National Wind Farm Development Guidelines released in 2009 [4] include recommendations for shadow flicker limits relevant to wind farms in Australia.

The Draft National Guidelines recommend that the modelled theoretical shadow flicker duration should not exceed 30 hours per year, and that the actual shadow flicker duration should not exceed 10 hours per year. The guidelines also recommend that the shadow flicker duration at a dwelling should be assessed by calculating the maximum shadow flicker occurring within 50 m of the centre of a dwelling.

The Draft National Guidelines provide background information, a proposed methodology and a suite of assumptions for assessing shadow flicker durations in the vicinity of a wind farm.

The impact of shadow flicker is typically only significant up to a distance of around 10 rotor diameters from a turbine [5] or approximately 1 km for a modern wind turbine. Beyond this distance limit the shadow is diffused such that the variation in light levels is not likely to be sufficient to cause annoyance. This issue is discussed in the Draft National Guidelines where it is stated that:

"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 National Guidelines therefore suggest a distance equivalent to 265 maximum blade chords[*] as an appropriate limit, which corresponds to approximately 800 to 1050 m for modern wind turbines (which typically have maximum blade chord lengths of 3 to 4 m). The UK wind industry and UK government consider that 10 rotor diameters is appropriate, which corresponds to approximately 800 to 1100 m for modern wind turbines which typically have rotor diameters of 80 to 110 m.

The Draft National Guidelines also provide guidance on blade glint and state that:

"The sun's light may be reflected form the surface of wind turbine blades. Blade Glint has the Potential to annoy people. All major wind turbine manufacturers currently finish their blades with a low reflectivity treatment. This prevents a potentially annoying reflective glint from the surface of the blades and the possibility of a strobing reflection when the turbine blades are spinning. Therefore the risk of blade glint from a new development is considered to be very low."

[*] The maximum blade chord is the thickest part of the blade.

4 SHADOW FLICKER AND BLADE GLINT ASSESSMENT

4.1 Shadow Flicker Overview

Shadow flicker may occur under certain combinations of geographical position and time of day, when the sun passes behind the rotating blades of a wind turbine and casts a moving shadow over neighbouring areas. When viewed from a stationary position the moving shadows cause periodic flickering of the light from the sun, giving rise to the phenomenon of 'shadow flicker'.

The effect is most noticeable inside buildings, where the flicker appears through a window opening. The likelihood and duration of the effect depends upon a number of variable factors as follows:

- Direction of the property relative to the turbine;
- Distance from turbine (the further the observer is from the turbine, the less pronounced the effect would be);
- Wind direction (the shape of the shadow will be determined by the position of the sun relative to the blades, which will be oriented to face the wind);
- Turbine height and rotor diameter;
- Time of year and day (the height of the sun in the sky);
- Weather conditions (cloud cover reduces the occurrence of shadow flicker).

4.2 Shadow Flicker Assessment Methodology

The number of hours of shadow flicker experienced annually at a given location can be calculated using a geometrical model which incorporates the sun path, topographic variation over the wind farm site and wind turbine details such as rotor diameter and hub height.

The shadow flicker calculations have been undertaken using a computational model of the wind farm. The model makes the following assumptions and simplifications:

- There are clear skies every day of the year;
- The turbines are always rotating;
- The blades of the turbines are always perpendicular to the direction of the line of sight from the specified location to the sun;
- The sun is modelled as a disc.

These simplifications mean that the theoretical results generated by the model are likely to be conservative.

The simulations have been carried out with a temporal resolution of 10 minute; if shadow flicker occurs in any 1 minute period, the model records this as 10 minutes of shadow flicker.

As discussed in section 3, it is generally accepted that shadow flicker from wind turbines is unlikely to cause annoyance at distances greater than approximately 10 rotor diameters, or 265 times the maximum blade chord, from a wind turbine. Considering the chosen turbine diameter of 114 m, the most conservative value corresponds to 10 rotor diameters, or 1140 m.

The geometry of the shadow flicker map can be characterised as a butterfly shape, with the four protruding lobes corresponding to slowing of solar north-south travel around the summer and winter solstices for morning and evening. The lobes to the north of the indicative turbine location result from the summer solstice and conversely the lobes to the south result from the winter solstice. The lobes to the west result from morning sun while the lobes to the east result from evening sun. When the sun is low in the sky, the length of shadows cast by the turbine increases, increasing the areas around the turbine affected by shadow flicker.

4.3 Factors Affecting Shadow Flicker Duration

Shadow flicker duration calculated in this manner overestimates the annual number of hours of shadow flicker experienced at a specified location for several reasons.

1. The wind turbine will not always be yawed such that its rotor is in the worst case orientation (i.e. perpendicular to the sun-turbine vector). Any other rotor orientation will reduce the area of the projected shadow, and hence the shadow flicker duration.

   The wind speed frequency distribution or wind rose at the site can be used to determine probable turbine orientation, and to calculate the resulting reduction in shadow flicker duration.

2. The occurrence of cloud cover has the potential to significantly reduce the number of hours of shadow flicker.

   Cloud cover measurements recorded at nearby meteorological stations may be used to estimate probable levels of cloud cover, and to provide an indication of the resulting reduction in shadow flicker duration.

3. Aerosols (moisture, dust, smoke, etc.) in the atmosphere have the ability to influence shadows cast by a wind turbine.

   The length of the shadow cast by a wind turbine is dependent on the degree that 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.

4. The modelling of the wind turbine rotor as a disk rather than individual blades results in an overestimate of shadow flicker duration.

   Turbine blades are of non-uniform thickness with the thickest part of the blade (maximum chord) close to the hub and the thinnest part (minimum chord) at the tip. Diffusion of sunlight, as discussed above, results in a limit to the maximum distance that a shadow can be perceived. This maximum distance will also be dependant on the thickness of the turbine blade, and the human threshold for perception of light intensity variation. As such, a shadow cast by the blade tip will be shorter than the shadow cast by the thickest part of the blade.

5. The analysis does not consider that 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.

6. The presence of vegetation or other physical barriers around a shadow receptor location may shield the view of the wind turbine, and therefore reduce the incidence of shadow flicker.

7. Periods where the wind turbine is not in operation due to low winds, high winds, or for operational and maintenance reasons will also reduce the shadow flicker duration.

4.4 Current Shadow Flicker Analysis

The modelling of shadow flicker at the proposed Capital II wind farm has been conducted for a 53 turbine layout provided by MLA, using the method described in section 4.2 above. The wind turbine has been modelled assuming all wind turbines are disc objects oriented perpendicular to the sun-turbine vector, representing the maximum duration for which there is potential for shadow flicker to occur.

An assumption has been made regarding the maximum length that a shadow cast by a wind turbine is likely to cause annoyance due to shadow flicker. The UK wind industry considers that 10 rotor diameters is appropriate [5], while the Danish wind industry suggests this distance is between 500 m and 1 km [6]. The Draft National Guidelines suggest a distance equivalent to 265 maximum blade chords as an appropriate limit, corresponding to approximately 800 to 1050 m for modern wind turbines. The maximum turbine rotor diameter being considered for the proposed Capital II wind farm is 114 m and GH has assumed that the maximum distance a shadow can be cast that will cause annoyance for an observer is equal to 10 rotor diameters, or a distance of 1140 m.

There are a number of effects which may reduce the incidence of shadow flicker, such as cloud cover and variation in turbine orientation, that are not taken into account in the calculation of the theoretical shadow flicker duration. Exclusion of these effects means that the theoretical calculation is conservative.

No attempt has been made to account for vegetation or other shielding effects around each shadow receptor in calculating the shadow flicker duration. Similarly, turbine shutdown has not been considered. It is therefore likely that the adjusted shadow flicker durations presented here can still be regarded as a conservative assessment.

4.5 Blade Glint

Blade glint involves the regular reflection of sun off rotating turbine blades. Its occurrence depends on a combination of circumstances arising from the orientation of the nacelle, angle of the blade, and the angle of the sun. The reflectiveness of the surface of the blades is also important. As discussed, blade glint is not generally a problem for modern wind turbines, provided the blades are coated with a non-reflective paint, and is not considered further here.

5 RESULTS OF THE ANALYSIS

The results are presented in the form of a shadow flicker map at 2 m provided separately to MLA. To produce this map GH has assumed that the maximum distance a shadow can be cast that will cause annoyance for an observer is equal to 10 rotor diameters, or a distance of 1140 m.

An assessment of the level of conservatism associated with the worst-case results by calculating the possible reduction in shadow flicker duration due to turbine orientation (based on the wind rose measured at the site) and cloud cover has not been undertaken.

5.1 Mitigation Options

Should shadow flicker become a problem, its effects can be reduced through a number of measures. These include the installation of screening structures or planting of trees to block shadows cast by the turbines, or the use of turbine control strategies which shut down turbines when shadow flicker is likely to occur.

6 CONCLUSION

An analysis has been conducted to determine the duration of shadow flicker experienced at shadow receptors in the vicinity of the proposed Capital II wind farm, based on the methodology proposed in the Draft National Guidelines. The results of the assessment are presented in the form of a shadow flicker map provided separately to MLA.

The possible reduction in shadow flicker duration due to turbine orientation (based on the wind rose measured at the site) and cloud cover has not been assessed in this analysis. Further, the calculation of the predicted actual shadow flicker duration does not take into account any reduction due to low wind speed, vegetation or other shielding effects around each house in calculating the number of shadow flicker hours. Therefore the values may be regarded as a conservative assessment.

Blade glint is not likely to cause a problem for observers in the vicinity of the wind farm provided non-reflective coatings are used on the blades of the turbines.

7 REFERENCES

1 "Influences of the opaqueness of the atmosphere, the extension of the sun and the rotor blade profile on the shadow impact of wind turbines", Freund H-D, Kiel F.H., DEWI Magazine No. 20, Feb 2002, pp43-51.

2 Email from L Dunphy, Infigen, to M Clifton-Smith, GH, 24 September 2010.

3 "Policy and planning guidelines for development of wind energy facilities in Victoria", Sustainable Energy Authority Victoria, 2009.

4 "National Wind Farm Development Guidelines – Public Consultation Draft", Environmental Protection and Heritage Council (EPHC), October 2009.

5 "Planning for Renewable Energy – A Companion Guide to PPS22", Office of the Deputy Prime Minister, UK, 2004.

6 "Shadow variations from Wind turbines", Danish Wind Industry Association, May 2003, viewed 3 Aug 2010, http://guidedtour.windpower.org/en/tour/env/shadow/shadow2.htm

Turbine ID[1]	Easting [m][2]	Northing [m][2]
1	727045	6117169
2	727000	6117021
3	726957	6116874
4	726913	6116724
5	726872	6116576
6	726833	6116429
7	726787	6116277
8	726748	6116127
9	726702	6115973
10	726658	6115828
11	726498	6115696
12	726337	6115563
13	726177	6115432
14	726016	6115300
15	727180	6112015
16	727166	6112322
17	727179	6111686
18	727183	6111387
19	725613	6110911
20	725519	6110770
21	725432	6110632
22	725351	6110492
23	725268	6110351
24	725179	6110216
25	725103	6110077
26	725187	6109823
27	725272	6109568
28	725357	6109314
29	725200	6109027
30	724546	6104716
31	724309	6106764
32	724718	6107786
33	724657	6107644
34	724603	6107499
35	724541	6107349
36	724481	6107203
37	724423	6107058
38	724371	6106909
39	724248	6106616
40	724189	6106476
41	724130	6106325
42	724041	6106096
43	723981	6105951
44	723918	6105802
45	723861	6105657
46	723813	6105520
47	723756	6105387
48	724934	6105353
49	724857	6105223
50	724776	6105097
51	724702	6104971
52	724623	6104844
53	724466	6104587

1 GH numbering
2 Coordinates given in the UTM zone 55, WGS84 datum.

Table 1. Proposed turbine layout for the Capital II Wind Farm.