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Renewable Power Ventures

Capital Wind Farm
Analysis of Potential Shadow Flicker Impacts

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1. Introduction

Shadow flicker (also referred to as light flicker) is used to describe the effect caused by the intermittent shadow cast by the rotating blades of a wind turbine. This report reviews the circumstances under which shadow flicker will occur in the vicinity of the proposed Capital wind farm (Figure 1) and assesses the impacts of these effects.

1.1 Effect of Shadow flicker

Shadow flicker is intermittent changes in lighting intensity of the field of vision (Verkuijlen & Westra, 1984). This phenomenon, which can occur in the vicinity of wind farms due to the moving turbine blades is mainly of concern where residences, public areas or roads fall in the shadow of a turbine. It is most likely to be a problem when the turbines are sited in built up areas, but may occur for rural residences.

For most people, shadow flicker is only a visual amenity issue but, for some, it can have health implications. If the frequency of the flicker is above 2.5 Hz, shadow flicker can become a potential health hazard for both photosensitive epileptics and a small percentage of non-epileptics in the population (Verkuijlen & Westra, 1984). Other sources state that it is uncommon for epileptics to be photosensitive at frequencies less than 5 Hz (The National Society for Epilepsy (UK), 2005). It should be noted, however, that these limits for shadow flicker are not based on studies of wind turbines.

In assessing the issue of shadow flicker in connection with the proposed development, the following three questions have been addressed.

- Is there a potential health risk?
- Does any residence, public place or road fall under the shadow of a turbine at any time and, if so, for how long?
- Will shadow flicker be a problem and, if so, how might it be mitigated?

During the daytime, a rotating turbine naturally has an intermittent shadow which, at certain times of the day, may fall across houses or roads. In certain circumstances, people located both indoors and outdoors may be distracted by this shadow flicker effect.

The turbine details on which this assessment is based are:
- a turbine rotation speed varying up to about 15.4 rpm and a three bladed turbine,
- an 80 metre hub height, and
- a blade diameter of 88 metres.

Based on this rotation speed the maximum frequency of the shadow flicker effect will be less than 1 Hz. This is well under the identified threshold for health problems.

Accordingly, shadow flicker associated with the proposed development will not pose a health problem.

1.2 Occurrence of shadow flicker

Shadow flicker occurs only during the day and at times when the turbines are rotating. The wind farm is comprised of up to 63 turbines and each may produce a localised shadow flicker affect. In general, any particular location affected by shadow flicker would only experience the shadow flicker of a single turbine. However, over the year, a particular location may be affected by different turbines at different times of the year.

The areas potentially affected by shadow flicker are those that may be in the shadow of the turbine during the course of the day. These areas vary throughout the day as the sun is seen to transit from east to west and as the elevation in the sky varies with the time of day and time of year.

1.3 Factors which may reduce the occurrence or intensity of shadow flicker

Shadow flicker only occurs during daylight hours. Cloud cover may reduce the effect of shadow flicker such that it is not noticeable. The intensity of the effect may also vary as:

- the sun occurs low on the horizon due to greater atmospheric absorption, particularly at times when there is significant amounts of airborne dust or moisture;
- the distance of the viewing site from the turbine increases;
- the angle of the turbine blades to the sun's rays increase, depending on wind direction;
- intervening structures such as trees may reduce the intensity of the effect.

A sun-chart (Appendix 1) for the relevant areas provides guidance as to the solar azimuth angle (Figure 3) and solar altitude angle (Figure 4) at different times of the day and throughout the year. Sun-charts are available for specific locations.

Using the appropriate sun-chart it is possible to calculate whether shadow flicker will affect specific locations, such as residences in the vicinity of turbines. Further analysis of the relative elevations of the turbines and ground locations together with consideration of blade diameter allows an estimation of the time of shadowing from the turbine.

2. Shadow Flicker Geometry

Shadow flicker may potentially occur in the vicinity of the proposed Capital Wind Farm at a few residences, and for some property access tracks. Several local roads may also be affected by shadow flicker for short periods. The intensity of the effect will decrease with distance from the turbine that causes the shadowing. Potentially affected residential locations have been assessed to determine the extent of shadow flicker effect for an 88 metre diameter turbine with an 80 metre hub height. The following describes the geometry considered and the parameters needed for analysis:

- Elevation(s) at the site of the wind turbine(s) (E_t);
- Elevation at each location that may potentially be affected (E_s);
- The solar azimuth angle, this angle is determined as shown in Figure 3;
- Distance between the wind turbine and the location under analysis (d);
- Height of the wind turbine tower (for this assessment hub height of 80 metres);
- Diameter of the turbine blades (in this case 88 metres); and
- Height of the top and base of the blades of the wind turbine (h_t and h_b).

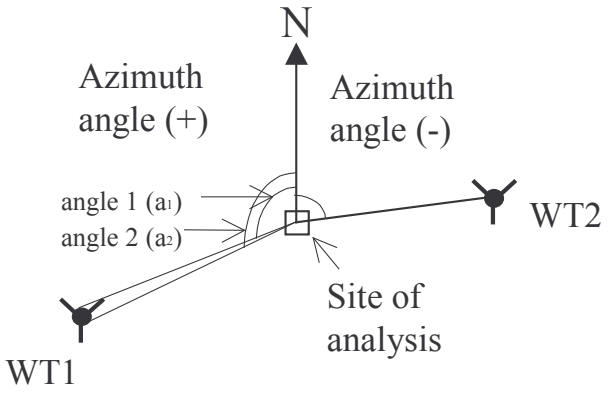

Figure 3 – Schematic of solar azimuth angle calculations

Notes:

1. The azimuth angle can be either a positive value or a negative value depending on the location of the wind turbine relative to the site of analysis as shown in Figure 3. If the wind turbine is situated to the west of the site of analysis the azimuth angle value is arbitrarily considered positive. Alternatively, if the wind turbine is situated to the east of the site of analysis then the azimuth angle is negative.

2. When determining the potential for shadow flicker at a single location (ie a house) the azimuth angle should also take into account the angular width of the turbine as subtended to the viewer at the house. This is done by measuring two values (a_1 and a_2) for the azimuth angle as shown in Figure 3 on the side of WT1. The analysis is more complex when measuring the potential for shadow flicker along a section of road.

The next step is to determine the solar altitude angle.

There are two values for this angle; θ_1 (top of blades) and θ_2 (base of blades) as shown in Figure 4.

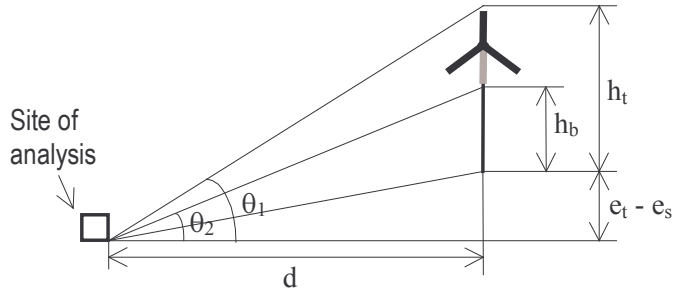

Figure 4 – Schematic for solar altitude angle calculations

To determine these values the following equations are used:

$$\theta_1 = \tan^{-1}\left[\frac{h_t + (e_t - e_s)}{d}\right] \text{ (degrees)}$$

$$\theta_2 = \tan^{-1}\left[\frac{h_b + (e_t - e_s)}{d}\right] \text{ (degrees)}$$

where: θ_1 = solar altitude angle 1
θ_2 = solar altitude angle 2
h_b = height of the base of the blades (in this case 36 metres)
h_t = height of the top of the blades ($h_t = h_b$ + turbine diameter (88 m), i.e. 124 metres)
e_t = elevation of the base of the tower
e_s = elevation of the site under analysis
d = distance between the base of the wind turbine tower and the site

For the purpose of this assessment the hub height is 80 metres and the turbine diameter is 88 metres. All length measurements are in metres. Determination of θ_1 and θ_2 assuming the turbine blades are perpendicular to line between the view point and the turbine, is simply a matter of the azimuth and allowance for angle θ_1 to θ_2 to reduce as distance increases.

Once the values for the solar azimuth angle and the solar altitude angle are known, the time period over which shadow flicker may occur can be determined. This can be done using a sun-path chart for the closest latitude value where the wind turbine site is situated. Sun-charts are available for many locations throughout NSW. The sun-chart for Canberra has been used for this assessment as the location is close to the wind farm.

The effects of shadow flicker may be experienced in the early morning for locations to the west of the wind turbines or in the late afternoon for locations to the east of individual wind turbines. All residences in the vicinity of the wind farm have been assessed in terms of potential for shadow flicker to occur.

While the Sunchart (Appendix 1) can be used to determine whether specific residences had potential to be affected by shadow flicker, the analysis provided in Section 3 gives a more qualitative review of circumstances determining the occurrence and intensity of shadow flicker.

3. Shadow Flicker Zones and Intensity

The previous section provided an explanation of the geometry involved in identifying the locations and times at which the shadow flicker effect may occur. This section provides a more qualitative review of factors that affect the intensity of the shadow flicker effect and also the locations around a turbine where the effect may be experienced.

3.1 Location of the shadow flicker zone

Figure 5(A) provides a graphical representation of the areas around a turbine that may be affected by the shadow flicker effect over a year. As can be seen the area west of the turbine has potential to be affected in the morning and areas to the east of a turbine may be affected in the afternoon. Also as shown in Figure 5(A), the zone affected is limited to the north and south of the turbine.

The winter extent occurs when the sun appears further to the north (Winter Solstice) compared to the summer extent when the sun appears further south (Summer Solstice).

At midday the sun is directly overhead and to the north (for a Southern Hemisphere location) and the shadow appears on the south side of the turbine. The length of the shadow increases to maximum in winter when the sun appears lower in the sky to the north.

For morning and afternoons when the sun is close to the horizon, (that is after sunrise or before sunset), there is a low angle of incidence which results in a longer shadow than occurs at midday.

Figure 5(A) also shows concentric lines around the turbine at 375 metres, 500 metres and 1,000 metres distance. The reduction in intensity of the shadow flicker effect with distance is described in Section 3.2

3.2 Reduction of shadow flicker intensity with distance

The distance from a turbine where the effect of shadow flicker can be considered to be ameliorated varies with equipment. For a turbine of the type to be used it is conservatively assumed that there will be negligible effect for distances greater than 1000 metres and only a partial effect between 400 metres and 1,000 metres.

The angular diameter of the sun is about 0.54^0 based on a diameter of 1.4×10^6 km at a distance of 1.49×10^8 km (Figure 5, part C). This will affect the extent of time that the shadow effect occurs at any location and the nature of the effect. At close distance, a blade may have a noticeable shadowing effect, but the extent of the effect will decrease with distance. For example, a 3.5 metre wide blade would need to be at a distance of only 375 metres to have the same angular width as the sun. Even at 375 metres the effect of atmospheric scattering of light is likely to mean that the shadow effect is not clearly defined. Beyond 375 metres the turbine blade is less than the angular width of the sun. In this situation, the shadow flicker effect may be considerably reduced in intensity.

The turbine blades are wider toward the centre of the turbine and that part of the blades represents a larger proportion of the swept area than the outer tip. Where the shadow flicker is produced by the thinner, outer part of the blade (Figure 5(B)), the period of time of shadowing is less than where the sun is obstructed by the more central and wider part of the turbine blade. Accordingly, the shadow flicker effect is likely to be more pronounced when the shadow results from the inner part of the turbine. However, if the shadowing were to be caused by the hub of the turbine, then the shadow of the hub and nacelle will be complete and the shadow flicker effect would not be apparent.

4. Review of potential for shadow flicker at selected locations

4.1 Shadow Flicker at Residences

Residences in proximity to the proposed Capital Wind Farm were assessed for their potential to be affected by shadow. The location of the shadow flicker zone for an individual turbine is shown in Figure 5 and was used to gain an appreciation of areas (residences and local roads) that could potentially be affected by shadow flicker. In addition, Connell Wagner PPI's Windfarmer software was used to identify areas of potential shadow flicker and assessment of the extent of the effect was also determined for selected residences. An analysis of the potential for the effect has been undertaken for each neighbouring residence and the results are provided Table 1 below. The assessment indicates that no neighbouring residences will be affected by Shadow Flicker. All are well beyond the distance where effects may be significant.

4.2 Effects on Local Roads and Public Places

As can be seen on the map included, Taylors Creek Road in some places is located less than 1 km to the east from some of the proposed wind turbine sites (notably Groses Hill Turbines 6–11) (Figure 2). This means that shadow flicker could affect the section of the road in late afternoons.

Given the distances between respective turbines and the road, the effect is considered to be insignificant.

There are no other public places that are likely to be affected by shadow flicker.

4.3 Factors which reduce the impact of shadow flicker

It is important to note the following in relation to the actual impact of shadow flicker.

1. The analysis using 'WindFarmer' software is conservative in that it represents the maximum time of effect.
2. Any cloud obscuring the sun at these times will reduce the time and intensity of the effect.
3. The effect itself will be minimised if the wind turbine blades are not facing the viewer "square on" and presenting the widest blade profile.
4. There will be no effect if the wind turbine is not operating.
5. The intensity of the effect is reduced by distance.
6. At the low solar altitude angles, the light is likely to be more diffuse and the effect less pronounced.
7. It is assumed there are no visual barriers between the wind turbine and the viewpoint, such as trees.

Table 1 – Details of Residences Assessed for Potential to be Affected by Shadow Flicker

Residence	Distance to Turbine (m)	Potential Time		Hours/year	Minutes on Worst Day	Mitigating factors	Zone of Potential Shadow Flicker	Potential Shadow Flicker Effect
		AM	PM					
Groses Hill Group (Eastern Side)								
Widgemore	1,300	No	No					None
Euroka Homestead	700	No	Yes	20	20	Tree screening by large pine trees	Only partial shadow flicker effect due to distance	Limited effect due to tree screening and distance
La Granja	1,600	No	Yes			Some trees	Outside zone	None
Sunnybrook 1, 2	1,300	No	Yes					None
Groses Hill Group (Western Side)								
Luckdale	1,200	Yes	No			House is surrounded by trees	Beyond shadow flicker zone	Unlikely to be significant issue due to distance and trees
Kullingrah	1,400					Houses are surrounded by trees	Beyond shadow flicker zone	Limited by tree screening & distance
Lakoona	2,300	No	No			Partial tree screening	Outside zone of effect	No Effect
Panhandle	1,000	No	No			Tree screening by mature pine trees	Outside zone of potential shadow flicker	No Effect
Ellenden Group (south – eastern side)								
Ellenden A & B	800	Yes	Yes	8	40	Tree Screening	Partial effect	Low potential reduced by screening
L'Orizon A	<100	No	Yes	494	240	Partial tree screening		High, but leased by RPV
L'Orizon B	< 300	No	Yes	113	80	No tree screening		High, but leased by RPV
E7	1,500	No	No			Tree screening	Outside zone of potential shadow flicker	Limited by trees and distance
Hammonds Hill Group (East)								
No residences affected	>1,500	No	Yes			Some tree screening. Additional tree planting	Beyond 2,000 metres	None due to distance & tree screening
Hammonds Hill Group (Western Side)								
Currandooley	2,100	Yes	No			Tree Screening and topography	Beyond 1,500 metres	None due to screening

Note: (1) Only calculated where turbines less than 1 kilometre from receptor.
(2) The period that the effect may occur is conservative and is reduced by factors described in Section 3.2

5. Conclusions

The potential for shadow flicker effect at residences and local roads surrounding the Capital Wind Farm has been assessed and results provided in this report. The shadow flicker effect has potential to occur within about 400 metres of the turbines and a partial effect may occur beyond that distance and diminish with distance. The timing of the effect also decreases with distance.

Two windfarmer residences, Euroka and Ellenden are located at 700 metres and 800 metres respectively from the nearest turbines. Euroka to the north-east of the Groses Hill Group may be partly affected by Shadow flicker for an estimated 20 hours. Ellenden residence is located to the south-east of the Ellenden Group and may be partly affected by Shadow flicker for an estimated 8 hours. Due to the distance from the nearest turbines and the thick screening by mature pines at both sites, the effect is considered to be negligible. The owners of the properties are also beneficiaries of the development and have leased their properties for the purpose of the wind farm development.

Residences at L'Orizon are within 300 metres of the wind turbines and would be subject to greater impact of shadow flicker. Due to their proximity to the wind farm these properties will be leased by Renewable Power Ventures.

No neighbouring residences to the wind farm properties will be significantly affected by the shadow flicker effects associated with the Capital Wind Farm.

The effect for local roads is predicted to be of a minor nature and is not considered to be associated with any safety risk.

Shadow flicker associated with the Capital Wind Farm will have limited and minor effect and does not require any mitigation measures.

6. References

Verkuijlen & Westra, 1984	Shadow Hindrance by Wind Turbines (University of Amsterdam)
The National Society for Epilepsy (UK), 2005	http://www.epilepsynse.org.uk/pages/info/leaflets/photo.cfm
Danish Wind Industry Association, 2003	http://www.windpower.org/en/tour/env/shadow/shadow2.htm

Attachments

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Appendix 1 – Sun-chart for Canberra