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Glen Innes Wind Power

Glen Innes 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 Glen Innes 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 18 rpm and a three bladed turbine,
- an 80 metre hub height
- a blade diameter of 100 metres (maximum diameter for the turbines under consideration)

Based on the maximum rotation speed and the three bladed turbines, 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 27 turbines and each may produce a localised shadow flicker effect. 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 its 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 and the intensity of the effect may also vary as:

- Cloud cover builds up reducing the intensity of sunlight reaching a viewpoint and hence the effect of shadow flicker to the extent where with heavy cloud cover it is not noticeable.
- the sun occurs low on the horizon and there is greater atmospheric absorption, due to the longer path through the atmosphere, 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 (depends on wind direction);
- intervening structures such as trees reduce the transmission of the sun's rays and themselves cast a fixed shadow.

Sun-charts are available for specific locations and provide 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. A sun-chart for Armidale is provided in Figure 5 as generally representative of these parameters for Glen Innes.

Using the appropriate sun-chart it is possible to calculate whether shadow flicker will affect specific locations, such as residences in the vicinity of wind turbines. Further analysis of the relative elevations of the turbines and ground locations together with consideration of blade diameter allows an estimation of the period of time that shadow flicker may occur at particular viewpoints from various turbines.

Due to the number of turbines at the Glen Innes site, the irregular variations in topography and varying movements of the sun throughout the year, the manual analysis of shadow flicker occurrence and duration at all potentially affected locations surrounding the wind farm would be a very time consuming task. Accordingly, the analysis for the whole wind farm has been undertaken using 'Wind Farmer' software and the results are provided in this report.

Despite the use purpose designed software for this task, the following sections outline the fundamental background to the analysis as a means to assist interested parties to understand the issue and perhaps review the predictions for their location of interest.

2. Shadow Flicker Geometry

Shadow flicker may potentially occur in the vicinity of the proposed Glen Innes Wind Farm at a few residences and for some property access tracks. Several local roads may also be affected by diffuse shadow flicker effect 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 a 100 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 100 metres)
- Height of the top and base of the blades of the wind turbine (h_t and h_b)

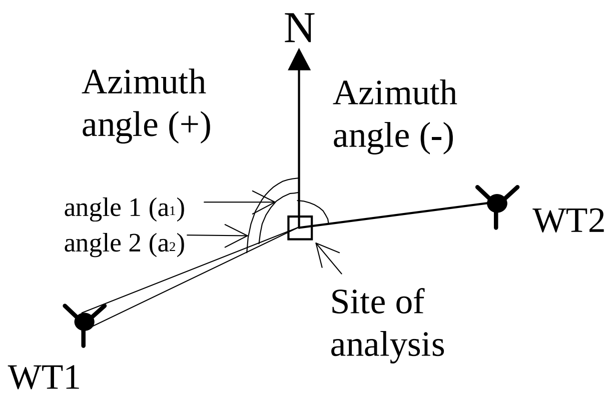

Figure 3 – Schematic of solar azimuth angle calculations

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.

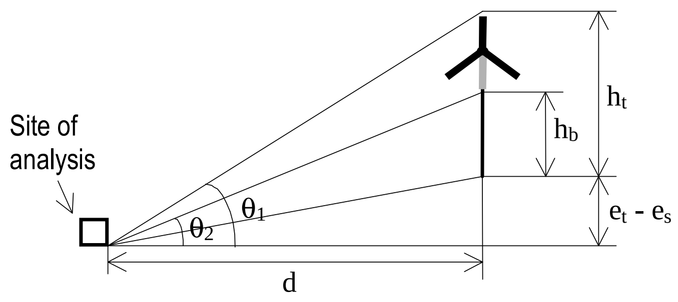

Figure 4 – Schematic for solar altitude angle calculations

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 (angle between horizontal at viewpoint and top of blades)
θ_2 = solar altitude angle 2 (angle between horizontal at viewpoint and base of blades)
h_b = height of the base of the blades (in this case 30 metres)
h_t = height of the top of the blades ($h_t = h_b$ + turbine diameter (100 m), i.e. 130 metres)
e_t = elevation of the base of the tower
e_s = elevation of the site under analysis (viewpoint or affected location, e.g. residence)
d = distance between the base of the wind turbine tower and the viewpoint

For the purpose of this assessment the hub height is 80 metres and the turbine diameter is 100 metres (the maximum diameter for turbines being considered for the project). 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 Armidale is shown in Figure 5 as being reasonably representative of the locality.

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.

Either the sun-chart in (Figure 5) or 'Wind Farmer' software can be used to determine whether specific residences have potential to be affected by shadow flicker, however other circumstances may affect the occurrence and intensity of shadow flicker as described in Section 3.

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 6(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 6(A), the zone affected is limited to the north and south of the turbine in relation to the path of the sun at different times of the year.

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 6(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 the dimensions of the turbine blades. 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 as indicated in the following paragraphs.

The angular diameter of the sun is about 0.54^0 based on the sun's diameter of 1.4×10^6 km and its location at a distance of about 1.49×10^8 km (Figure 6, 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, the widest part of a blade (i.e about 3.5 metres) 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 thickest part of the turbine blade is less than the angular width of the sun. Accordingly with increasing distance beyond 375 metres, the shadow flicker effect is likely to 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 do the outer tips that are widely separated. The circumference of the area swept by the blades of a 100 metre turbine is 314 metres and the blade tips may represent about 1% of this length. Where the shadow flicker is produced by the thinner, outer part of the blade (Figure 6(B)), the period of time of shadowing (< 1% of the time for each full rotation) is less than where the sun is obstructed by the wider part of the turbine blade closer to the hub which may be of the order of 20% of the time taken for a full rotation. 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. From the foregoing discussion it can be seen that the observed shadow flicker effect at any location may vary as the sun's rays are intercepted by different parts of the turbine.

4. Review of potential for shadow flicker at selected locations

4.1 Shadow Flicker at Residences

Residences in proximity to the proposed Glen Innes 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 6 and was used to gain a general appreciation of areas (residences and local roads) that could potentially be affected by shadow flicker throughout the year. In addition, Connell Wagner's 'Windfarmer' software was used to identify all areas surrounding the wind farm where potential for shadow flicker exists and the duration of the effect for selected residences.

An analysis of the potential for the effect has been undertaken for each neighbouring residence within two kilometres and the results are provided Table 1 below. The assessment indicates that no neighbouring residences will be significantly affected by Shadow Flicker. Figure 6 shows a graphical analysis of the distribution of the shadow flicker effect and the duration that the effect may occur over a year for residences within one kilometre. 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, the Gwydir Highway will not be affected by a shadow flicker effect (Figure 6). Most local roads are more than 1 km from the nearest turbine and accordingly will not be subject to any significant shadow flicker effect. The only exception is the low use local road that runs between the Furracabad and Wellingrove Valleys where it crosses the Waterloo Range within the wind farm site. This means that shadow flicker could affect the section of the road at various times during the year. Due to the low usage of this road and the low speeds associated with the narrow and winding track, the shadow flicker effect is unlikely to present a safety hazard.

Given the distances between respective turbines and most of the local roads, the effect in relation to vehicles using local roads is considered to be insignificant.

Sinclair Lookout has been assessed as being to the north of the shadow flicker zone associated with the closest turbine, Turbine no. 1.

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

The results of the analysis presented in Table 1 show the times that shadow flicker may apply for specific locations. However, 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 the times when conditions are sun that shadow flicker may occur 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 times of low solar altitude, the sunlight is likely to be more diffuse and the effect less pronounced.
7. For this assessment it has been assumed there are no visual barriers between the wind turbines and the viewpoint, such as trees, which is not always the case.

Table 1 – Details of Residences surrounding the wind farm, assessed for potential to be affected by Shadow Flicker (within 2 kilometres)

Residence	Distance to nearest Turbine (m)	Potential Time		Hours / year (1)	Minutes on Worst Day (2)	Mitigating factors	Zone of Potential Shadow Flicker	Comment on Extent of Shadow Flicker Effect
		AM	PM					
Eungai	1,567	No	Yes	-	-	Partial tree screening	Partial effect	Limited effect due to distance
Glengyle	1,095	Yes	No	-	-	Tree screening by mature trees	Partial effect	Limited effect due to screening
Highfields	956	No	Yes	0	0	Partial tree screening	Partial effect	Limited effect due to house location and tree screening
Hillside	787	No	Yes	0	0	House is surrounded by trees	Partial effect	Limited effect due house location and tree screening. Residence is vacant and in poor condition
Illparran A	1,541	Yes	No	-	-	Partial tree screening	Partial effect	Limited effect due to distance, location and tree screening
Illparran B	1,350	Yes	No	-	-	Partial tree screening	Partial effect	Limited effect due to distance and screening by trees
Lombardy	1,920	No	Yes	-	-	Partial tree screening	Partial Effect	Limited effect due to distance and screening
Mayvona	853	No	Yes	10	20	Partial tree screening	Partial effect	Limited effect due to screening by trees. Residence is vacant and in poor condition
Rivoli	1,849	Yes	No	-	-	-	Beyond shadow flicker zone	No effect due to location to the north of the indicated shadow flicker zone.
Sinclair Lookout	320	Yes	No	0	0	-	Beyond shadow flicker zone	
Wattle Vale	1,902	No	Yes	-	-	-	Beyond shadow flicker zone	

Note: (1) Only calculated where turbines are less than 1 kilometre
(2) The period that the effect may occur is conservative and is reduced by factors described in Section 4.3

5. Conclusions

Shadow flicker will occur in the vicinity of the wind turbines with the full intensity of the effect being limited to within about 400 metres of the turbines and decreasing with distance. Beyond that distance both the intensity and the duration of the effect decrease progressively and beyond one kilometre the effect is considered insignificant.

The speed of rotation of the turbines is such that the frequency of the shadow flicker effect is less than the threshold level that may produce health effects for a small percentage of the population.

The potential for shadow flicker effect at residences and local roads surrounding the Glen Innes Wind Farm has been assessed and results are provided in this report. The period of the effect also decreases with distance.

There are three residences, Highfields, Mayvona and Hillside, which are located within 1 kilometres of the proposed windfarm. As illustrated in Figure 6, Mayvona is the only residence that falls within a shadow flicker zone, with an expected 10 hours of shadow flicker effect per year. On days with potential for shadow flicker effect to occur at Mayvona, the maximum duration of the effect will be 20 minutes during the late afternoon when the sun is to the west. Occurrence duration would be reduced where cloud cover negates the effect. Mayvona is currently vacant and is in a state of disrepair.

Hillside and Highfields are also within one kilometre of the nearest turbine however their locations are such that they will not be subject to shadow flicker effects. No other neighbouring residences to the wind farm properties will be significantly affected by the shadow flicker effects associated with the Glen Innes Wind Farm.

The effect for local roads is predicted to be of a minor nature and is assessed as not presenting any safety risk.

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

6. References

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Attachments