Section 20
Shadow Flicker Report

20.0 SHADOW FLICKER

Shadow flicker from wind turbines is the effect resulting from the shadows cast by the rotating blades of the turbine on sunny days. The effect may be more or less pronounced depending on the intensity of the sun/shadow contrast and the distance from the turbines to a receptor. The effect is most pronounced during sunrise and sunset on clear days and on receptors closer than 1,000 feet to a turbine.[1]

The 48 turbine sites were modeled using the Windpro software model. This software is designed to simulate the path of the sun over the course of a year in order to predict the area where shadow flicker is likely to occur. It is a worst case prediction, assuming the sun is shining all day each day, and does not take into account the substantial effect that vegetation screening would provide between a turbine and a receptor. It also assumes that the turbines are perpendicular to the receiver and are always operating. See Appendix 20-1 for the complete shadow flicker report and illustrative maps.

The analysis concludes that only four locations will experience any shadow flicker under these worst case conditions.[2] When corrected to apply common weather conditions, none of these four receptors are likely to receive more than eight hours of shadow flicker in a calendar year, and even this corrected calculation predicts an impractical result because of the substantial effect intervening vegetation will have to further limit potential shadow flicker.

[1] Environmental Impacts of Wind Energy Projects, National Academies Press, 2007, p. 160.
[2] Subsequent to completing the flicker analysis it was determined that "Structure AF", as discussed in the report, is not a residence but instead is two adjacent construction trailers.

Appendix 20-1

Memo

To:	Jonathan Ryan	From:	Theo Kindermans
	Stantec Consulting Ltd. Topsham, ME		Stantec Planning and Landscape Architecture, PC Boston, MA
File:	Highland Wind Project	Date:	December 8, 2009

Reference: Shadow-Flicker Modeling
Highland Wind Project, Highland Plantation, Maine

Introduction

This memorandum provides a brief explanation of the shadow-flicker phenomenon, the modeling approach employed for the site in Highland Plantation, ME and relevant explanations and results. The site layout was provided by the Stantec Consulting Ltd. from Topsham, ME, showing 48 Siemens SWT-2.3 turbines with an 80 meter high hub. It is assumed that all turbines will be constructed with the largest blades this turbine can be outfitted with. The shadow flicker calculation shows a 101 meter rotor diameter.

Shadow-Flicker Background

Shadow-flicker from wind turbines can be defined as short reductions in light intensities caused by the rotating blades of the turbine casting shadows on receptors on the ground and stationary objects such as a window at a residence. When the sun is obscured by clouds or heavy fog, or when the turbine is not operating, no shadows will be cast.

Shadow-flicker can occur on project area receptors when the wind turbine is located near the receptor and when the turbine blades interfere with the angle of the sunlight. The most typical effect is the visibility of an intermittent light reduction on the receptor facing the wind turbine and subject to the shadow-flicker. Obstacles such as terrain, trees, or buildings between the wind turbine and a potential shadow-flicker receptor significantly reduce or eliminate shadow-flicker effects. No shadow flicker is present when the rotor of the turbine is perpendicular to the receptor.

Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. Shadow flicker intensities diminish with increased distance from turbine to receptor and with lower visibility weather or atmospheric conditions such as haze or fog. Closer to a turbine the shadow will appear to be darker and wider as the rotors will block out a larger portion of sunrays. Further from the turbine the shadow will be less intense or lighter, and less distinct.

The spatial relationship between a wind turbine and a receptor, as well as wind direction are key factors related to shadow-flicker time. Shadow-flicker time is most commonly expressed in hours per year. Shadow flicker is most pronounced at distances from the turbine of less than1,000 ft and during sunrise and sunset when the sun's angle is lower and the resulting shadows are longer. Shadow flicker is typically problematic for short periods each day – rarely more than a half-hour at sunrise and at sunset. The phenomenon is more noticeable in the winter than the summer due to the sun's lower position on the horizon in winter months in North America (NAS, 2007).

Reference: Shadow-Flicker Modeling

The analysis provided in this report does not evaluate the shadow intensity, but rather focuses on the total amount of time (hours and minutes per year) that shadow flicker can potentially occur at receptors regardless if the shadow flicker is barely noticeable or clearly distinct. As a result, it is likely that receptors will experience less shadow-flicker impact than modeled and reported, especially those that are further away from the turbines. It is very likely that marginally affected receptors may not be able to identify shadow-flicker at all as the shadows will get more diffuse with increased distance

The speed of the rotor and the number of blades determine the frequency of the flicker of the shadow. The shadow-flicker results in this memo are based on Siemens SWT-2.3 3-blade, with a turbine height of 80 meters. The diameter of the rotors is assumed to be 101 meters; the largest blade size for this hub. The rotor speed for this turbine will be between 6 and 16 RPM which translates in a maximum blade frequency of approximately .8 Hz (less than 1 alternation per second).

Modeling Approach

For the shadow flicker modeling a module of the Windpro software has been used. The computer model simulates the path of the sun over the course of the year and assesses at regular intervals the possible shadow flicker across a receptor. The color coded map that was produced by the computer model, shows a very conservative estimate of the number of hours per year that shadows could be cast by the rotation of the turbine blades.

A near worst case approach has been adopted for reporting the shadow flicker results. This worst case scenario includes the following assumptions for sun and wind:

- The sun is always shining, from sunrise to sunset.
- The rotor plane is always perpendicular to the line from the turbine to the sun. This means that the wind blows either directly from or towards the sub, and that the wind direction moves with the moving of the sun.
- The turbine is always operating.

Furthermore, specific local conditions as vegetation, cloud and fog patterns are not taken into account and most likely will further reduce shadow flicker impacts. The analysis assumes windows are situated in direct alignment with the turbine-to-sun line of sight. Even when windows are so aligned, the analysis does not account for the difference between windows in rooms with primary use and enjoyment (e.g. living rooms) and other less frequently occupied or un-occupied rooms or garages.

The shadow-flicker model uses the following input:

- Turbine locations
- Shadow flicker receptor (residence) locations (coordinates)
- USGS 1:24,000 topographic and USGS DEM (height contours)
- Turbine rotor diameter
- Turbine hub height
- Joint wind speed and direction frequency distribution
- Sunshine hours (long term monthly reference data)

The model calculates detailed shadow flicker results at each assessed receptor location and the amount of shadow-flicker (hours per year) everywhere surrounding the project. A receptor in the model is defined as a 1 square meter 1 meter above ground level. This omni-directional approach produces shadow-flicker results at a receptor regardless of the direction of windows and provides similar results as a model with windows on various sides of the receptor.

The sun's path with respect to each turbine location is calculated by the software to determine the cast shadow paths every minute, daily over one full year.

The turbine run-time and direction (seen from the receptor) are calculated from the site's long-term wind speed and direction distribution.

Output from the model includes the following information:

- Calculated shadow-flicker time at selected receptors,
- Tabulated and plotted time of day with shadow flicker at receptors,
- Tabulated time of impact from each turbine at a receptor
- Map showing turbine locations, selected shadow-flicker receptors and color-coded contour lines indicating projected shadow-flicker time (hours per year).

Conclusion

As previously stated, the shadow-flicker model assumptions applied to this project are very conservative and as such, the analysis is expected to over-predict the impacts. Additionally, many of the modeled shadow flicker hours are expected to be of very low intensity.

Of the modeled 106 receptors, only four receptors potentially receive shadow flicker. All other modeled receptors do not show any impact of shadow flicker.

The statistics of the potentially impacted receptors are outlined below:

Receptor name	Shadow hours per year, hours:minutes / year	Shadow days per year	Maximum shadow hours per day
A	41:25	123	0:26
B	33:25	75	0:39
AF	16:22	90	0:14
CS	29:05	113	0:22

There are no guidelines in Maine or the US that set limits of acceptable shadow flicker impacts. Internationally there are some commonly accepted standards that could be used as a guideline for the above calculation. The international guidelines suggest an acceptable level is less then 10 hours per year in the case of Denmark, or less then 8 hours in the case of Germany and Sweden of real shadow flicker (weather dependant). However, these guidelines relate to weather dependant shadow flicker, and not worst case scenario as has been calculated above. Danish research has shown that approximate 18% of the time of the worst case scenario there will actually be shadow flicker after cloud cover, wind speed, wind direction are taking into account (windpower.org).

Applying the 18% factor to the hours per year in this project, taking into account the dense vegetation around some of the receptors and the distance of the receptors from the turbines (well in excess of 1000'), the impacted receptors will fall below commonly accepted standards for real shadow flicker hours per year.

In conclusion, there will not be any significant shadow flicker impact on the receptors identified in this report. For clarifications and more detailed analysis of expected influence at selected receptors please do not hesitate to contact me.

STANTEC PLANNING AND LANDSCAPE ARCHITECTURE P.C.

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Attachment: shadow flicker maps

c. file

Highland Wind Project
Highland PLT, Maine

Shadow Flicker Study - Eastern Project Area

Date 10.16.2009

Created by: ZYY
Filename: V:\1956\active\195600385\design\Shadow flicker study\24x36-eastern project area.mxd

Data Source: Aerial from 2007 National Agriculture Imagery Program (NAIP) aerial orthoimagery

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