APPENDIX M

Shadow Flicker Report

Shadow Flicker Study
Philip Wind Project
Haakon County, South Dakota

17 April 2023

Prepared for:

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1.0 INTRODUCTION

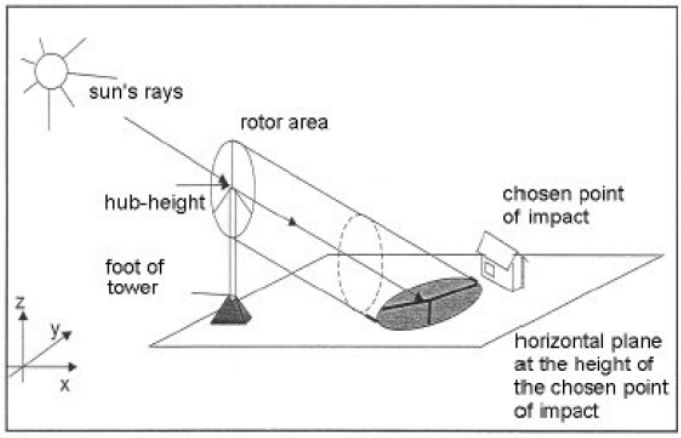
Philip Wind Partners LLC ("Philip Wind") is proposing to develop an approximately 300-Megawatt (MW) wind power generation facility in Haakon County, South Dakota. The proposed Philip Wind Project (the "Project") application proposes 95 possible wind turbine generator ("WTG" or "turbine") locations. The Project is located north of the city of Philip, South Dakota. Philip Wind retained Stantec Consulting Services Inc. (Stantec) to conduct an analysis of potential shadow flicker from the proposed Project wind turbines. The analysis considers the primary Project layout of 95 Vestas V163-4.5 MW wind turbines. Potential shadow flicker on inhabited dwellings within approximately 1.25 miles of proposed Project turbine sites was assessed and the results are summarized herein.

2.0 SHADOW FLICKER AND REGULATIONS

2.1 DESCRIPTION OF SHADOW FLICKER

Shadow flicker is a term used to describe the intermittent change in the intensity of light cast on an area resulting from the rotation of an operating wind turbine's blades between the sun and a stationary object. The presence and intensity of shadow flicker are dependent on many factors, including but not limited to the position of the sun in relation to the turbine and receptor, distance of receptor from turbine, physical characteristics of the turbine and blades, time of day, season of year, and topography of the Project area. Shadow flicker will only occur during daylight hours, when skies are not overcast or cloudy. Turbines must be operational, as the flicker effect is caused by rotation of the blades as they intercept the sunlight cast on a receptor. When a turbine is not operating it may cast a stationary shadow, similar to other objects such as trees or utility poles.

The amount of shadow flicker received in an area is dependent on the alignment of the rotor blades in relation to the sun and receptor. Maximum shadow flicker is received when the sun is aligned with the turbine and receptor, and the turbine's rotor plane is perpendicular to the receptor. This alignment occurs when the wind is blowing directly from a source turbine towards a receptor. At times when the wind is blowing from other directions, the shadow cast on the target receptor is diminished and the shadow flicker effect passes more quickly.



Shadow flicker also diminishes as the distance between the source turbine and receptor increases. It is generally accepted that flicker becomes imperceptible beyond approximately 1,500 meters (4,921 feet). For turbines with a rotor diameter less than 150 meters the flicker effect is less pronounced due to dissipation and the relative ratio of the turbine blade to the sun disk area at distances between approximately 10 times the rotor diameter and 1,500 meters.

2.2 REGULATIONS WITHIN THE PROJECT AREA

No regulations regarding shadow flicker have been identified for Haakon County or the state of South Dakota. However, Philip Wind has designed the Project to limit the amount of shadow flicker that is expected to fall on inhabited dwellings or other community structures considered sensitive (e.g., churches, schools) to 30 hours or less per year. Structures such as barns, agricultural buildings and commercial businesses were not included in the study.

Philip Wind has conducted this study to better understand the shadow flicker that may affect area receptors due to the normal operation of the proposed Project. They have considered shadow flicker in designing the current layout and seek to minimize flicker on sensitive receptors to the extent practicable.

3.0 SHADOW FLICKER ANALYSIS

The potential amount of shadow flicker on inhabited dwellings (also referred to as receptors) within the Project area was modeled using the Shadow module of EMD's WindPRO Version 3.6 software. WindPRO is an industry-accepted modeling program that calculates the number of hours per year that any given receptor may receive shadow flicker from the source turbines. The application considers the attributes and positions of the wind turbines in relation to receptors within the area. Shadow flicker models also consider the sun's position as it passes through the Project area each day in addition to regional climatological information.

Philip Wind requested a shadow flicker analysis on their current Project layout consisting of 95 potential locations of Vestas V163-4.5 MW turbines. The turbines have a 163 meter rotor diameter and a 98-meter hub height. The results of total shadow flicker for the analysis include expected shadow flicker due to the operation of turbines at the 95 proposed sites.

3.1 SHADOW FLICKER ANALYSIS METHODS

A modeling analysis was completed to assess the expected shadow levels at receptors based on a series of assumptions. The WindPRO model calculates both a "potential" and "expected" scenario. The "potential" scenario provides the periods when shadow flicker *may* occur on a receptor; however, it is not representative of the shadow flicker that is expected to occur. The "potential" scenario assumes no cloud cover, the sun is always shining during daylight hours, and turbines are always operating and rotated to cast maximum shadow on a receptor. The "expected" amount of annual shadow flicker considers the percentage of sunshine based on local regional sunshine statistics; the alignment of the blades in relation to the receptor due to wind direction; and the amount of time that the blades would not be rotating due to wind speeds outside of the turbine's operating parameters. The "potential" scenario, as described, could not realistically occur; however, is useful as an indicator of the potential times within which shadow flicker may occur. The shadow flicker analysis uses a conservative 90% operational time for purposes of calculating the annual hours of expected shadow flicker.

The results provided in this report include the expected amount of shadow flicker annually on each receptor, given the climatological conditions of the area as previously described. Climatological information was acquired from the National Climatic Data Center (NCDC) and regional meteorological stations. The percentage of sunshine probability was estimated from an analysis of average sunshine statistics for the Project region.

The climatologically based expected hours of sunshine for the Project area are presented in Table 1. The frequency of wind (hours per year) expected in 16 compass directions is summarized in Table 2. The total number of hours that turbines are able to cause shadow flicker takes into account non-operational time due to low or high wind speeds. The turbine types that Philip Wind proposes to use will generally operate when hub-height wind speeds are between 3 meters per second (m/s) and 30 m/s.

Table 1 Sunshine Probability (sun hours/possible sun hours)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.57	0.62	0.63	0.60	0.63	0.69	0.74	0.73	0.68	0.60	0.54	0.55

Table 2 Turbine Operation Time per Sector (hours per year)

0	22.5	45.0	95.5	90.0	112.5	135.0	157.5	180.0	202.5	225.0	247.5	270.0	292.5	315.0	337.5
473	237	158	158	237	394	552	473	355	355	315	315	473	1,104	1,418	895
TOTAL		7,884													

The effect of shadow flicker is also dependent on the physical characteristics of the turbine model and the distance between the source turbine and shadow receptor. The proposed Vestas V163-4.5MW turbines will have a rotor diameter of 163 meters (534.7 feet) and hub heights of 98.0 meters (321.5 feet). The individual locations of the wind turbines are based on the current layout of the Project. Elevations for turbines and receptors located within approximately 1.25 miles (2,012 meters) of the turbines were calculated using the National Elevation Dataset digitally acquired from the U.S. Geological Survey.

A total of 16 potential receptors (inhabited residences, schools, hospitals, churches, and cemeteries) within 1.25 miles of the proposed turbine locations were identified by Philip Wind and Stantec utilizing aerial imagery and on-site reconnaissance. Ten (10) of the 16 receptors are owned by participants in the Project. The coordinates (UTM Zone 14) of turbine and receptor locations are included in Appendix A and Appendix B, respectively.

The model utilizes a “greenhouse” approach which defines each receptor as a one-meter glass cube, representing a window able to receive shadow from all directions. Vegetation surrounding receptors may block or diminish the effect of shadow flicker.

Shadow flicker is widely considered imperceptible at a distance greater than 1,500 meters; however, Stantec conservatively analyzed the impact at all distances when more than 20 percent of the sun would be covered by a turbine blade. Shadow flicker does not occur when the sun-angle is less than three degrees above the horizon, due to atmospheric diffusion.

3.2 SHADOW FLICKER ANALYSIS RESULTS

The amount of shadow flicker on receptors within the Project area was calculated based on the climatological history of wind speed, wind direction and percentage of sunshine for the turbine models described in Section 3.1. Potential blocking of shadow flicker due to vegetation adjacent to a dwelling was not considered in this analysis.

Results of the analysis indicate that the majority of the 16 potential receptors analyzed within approximately 1.25 miles of turbines are expected to receive 10 hours or less of shadow flicker each year. Approximately 11 receptors are expected to receive between 0 and 10 total hours of annual shadow (Table 3). Three (3)

receptors are expected to receive between 10 and 20 hours of shadow flicker per year with two (2) expected between 20 and 30 annual hours.

A detailed table of receptor locations and expected annual shadow flicker results is included in Appendix B. Figure 1 presents a map of the Project area along with the expected shadow flicker hours per year if turbines were constructed and operational at all 95 primary proposed turbine locations.

Table 3 Shadow Flicker Analysis Summary (95 Turbine Locations)

Expected Annual Shadow Flicker Hours	Number of Receptors
Less than 10	11
10 – 20	3
20 – 30	2
Greater than 30	0

Detailed tabular shadow flicker results of both the shadow flicker analysis are provided in Appendix B and include the following information.

- Receptor identification number
- Coordinates of receptor location (UTM-Zone 14)
- Participation status in the Project
- The expected annual hours of shadow flicker at receptor

4.0 CONCLUSION

Potential shadow flicker from the Philip Wind Energy Project on inhabited residences and other sensitive receptors within approximately 1.25 miles of potential turbine locations was assessed using WindPRO's Version 3.6 Shadow Module software. Analyses were completed for a total of 95 turbines on 16 sensitive receptors.

Results of the shadow flicker analysis demonstrate that the Project can be operated in compliance with Invenergy's standards regarding the shadow flicker on sensitive receptors identified in relation to the Project.

FIGURES

Figure No.
1

DRAFT

Title
Shadow Modeling Results
Annual Hours - Expected Shadow Flicker

Client/Project
Invenergy, LLC
Philip Wind Project
Shadow Analysis

193709483

Project Location
Haakon Co., SD

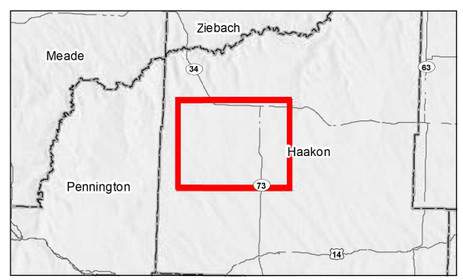
Prepared by JM on 2023-04-13
TR by AS on 2023-04-13
IR by XX on 2023-XX-XX

N

0 4,000 8,000 Feet
(At original document size of 11x17)
1:96,000

Legend
- Wind Turbine Location
- Sensitive Receptor

Shadow Results
Expected Annual Hours
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 45



Notes
1. Coordinate System: NAD 1983 UTM Zone 14N
2. Data Sources: Stantec, Invenergy, USGS, NADS
3. Background: 2021 NAIP

Stantec

APPENDICES

Appendix A Philip Wind Energy Center - Potential Turbine Locations

Turbine Identification	X (UTM 17)	Y (UTM 17)
T-001	278,953	4,916,432
T-002	279,062	4,916,934
T-003	279,806	4,917,015
T-004	277,421	4,919,621
T-005	277,290	4,919,088
T-006	279,071	4,914,793
T-007	278,716	4,914,301
T-008	278,328	4,912,592
T-009	278,247	4,913,554
T-010	278,034	4,913,192
T-011	279,307	4,912,428
T-012	277,361	4,911,512
T-013	277,997	4,911,819
T-014	279,202	4,911,601
T-015	277,134	4,910,804
T-016	278,760	4,910,602
T-017	279,250	4,910,861
T-018	278,115	4,909,768
T-019	277,975	4,909,232
T-020	279,042	4,908,888
T-021	276,094	4,908,511
T-022	277,918	4,908,477
T-023	276,260	4,907,923
T-024	277,845	4,907,428
T-025	278,299	4,907,713
T-026	279,021	4,907,925
T-028	284,382	4,909,786
T-029	283,041	4,910,336
T-030	283,755	4,910,384
T-031	283,131	4,909,606
T-032	284,151	4,909,433
T-033	282,670	4,909,298
T-034	281,138	4,907,456
T-035	281,644	4,907,959
T-036	282,072	4,908,388
T-037	283,512	4,907,241
T-038	278,366	4,918,774
T-039	277,238	4,918,508
T-040	278,351	4,918,093
T-041	277,653	4,917,679
T-042	277,246	4,917,311
T-044	269,753	4,905,319
T-045	270,225	4,905,590

Turbine Identification	X (UTM 17)	Y (UTM 17)
T-046	270,368	4,902,963
T-047	270,808	4,903,283
T-048	293,257	4,904,508
T-049	272,066	4,902,258
T-050	273,166	4,902,059
T-051	273,707	4,902,284
T-052	273,283	4,902,971
T-053	273,665	4,903,461
T-054	274,060	4,903,900
T-055	274,131	4,904,440
T-056	275,245	4,904,217
T-057	275,737	4,904,481
T-058	276,241	4,904,722
T-059	275,510	4,907,004
T-060	276,536	4,905,894
T-062	276,739	4,907,005
T-067	282,606	4,906,387
T-068	282,523	4,905,775
T-069	282,501	4,905,134
T-073	285,104	4,905,551
T-074	285,208	4,905,962
T-075	287,753	4,906,292
T-076	287,612	4,905,696
T-077	288,335	4,906,565
T-078	289,234	4,906,552
T-079	290,127	4,906,526
T-080	289,977	4,905,534
T-081	290,625	4,905,716
T-082	290,437	4,904,735
T-083	291,392	4,904,824
T-084	291,830	4,905,341
T-085	290,655	4,904,053
T-086	291,462	4,904,025
T-087	292,436	4,903,762
T-088	292,871	4,904,139
T-089	276,513	4,910,637
T-090	276,550	4,910,031
T-091	276,301	4,909,051
T-092	265,824	4,902,186
T-093	266,313	4,902,468
T-094	267,202	4,902,485
T-095	269,697	4,900,613
T-096	277,228	4,903,846

APPENDIX A

TURBINE COORDINATES

Appendix A Philip Wind Energy Center - Potential Turbine Locations

Turbine Identification	X (UTM 17)	Y (UTM 17)
T-097	277,160	4,903,324
T-098	277,182	4,902,817
T-101	274,566	4,906,230
T-102	279,743	4,918,305
T-103	279,765	4,917,586
T-104	281,602	4,906,780
T-105	285,176	4,906,595
T-106	286,440	4,903,180
T-108	276,288	4,909,618

APPENDIX B

RECEPTOR COORDINATES AND EXPECTED ANNUAL SHADOW HOURS

Appendix B - Philip Wind Energy Center
Receptor Coordinates and Expected Annual Shadow Flicker

Rec ID[1]	X (UTM 17)	Y (UTM 17)	Expected Shadow (Annual Hours)
R-002-P	286,785	4,902,305	0:00
R-003-P	287,012	4,903,919	0:00
R-008	285,818	4,910,305	3:54
R-009-P	284,768	4,908,594	3:12
R-010-P	282,281	4,906,984	28:15
R-011	280,731	4,908,411	18:16
R-012	280,170	4,907,197	26:03
R-013-P	280,766	4,912,369	5:27
R-015-P	274,435	4,907,683	13:33
R-016-P	271,187	4,905,980	6:34
R-026-P	271,208	4,905,926	6:55
R-027	271,850	4,900,914	0:00
R-033	280,512	4,920,071	0:00
R-070-P	284,706	4,908,341	0:00
R-149-P	271,023	4,905,998	9:32
R-248	276,690	4,920,342	12:29

[1] "-P" denotes participation in the Project