Attachment B – Shadow Flicker Analysis for the Rugby Wind Repower Project

Jacobs

Memorandum

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Subject	**Shadow Flicker Analysis for the Rugby Wind Repower Project**
Attention	Manuela Elizondo/Avangrid Renewables, LLC
From	Mark Bastasch, P.E. (OR), INCE Bd. Cert./Jacobs Engineering Group Inc.
Date	January 24, 2024

1. Introduction

Rugby Wind, LLC (Rugby Wind), a wholly owned subsidiary of Avangrid Renewables, LLC, operates the Rugby wind farm (Facility) in Pierce County, North Dakota. The Facility began commercial operations in 2009 and has a nameplate capacity of 149.1 megawatts (MW). Facility components include 71 Suzlon S88 wind turbines with a capacity of 2.1 MW each, access roads, buried and overhead electrical collection lines, an electrical substation, an operations and maintenance building, a meteorological tower, and an aircraft detection lighting system. Additionally, a 9.5-mile-long, 230-kilovolt transmission line runs from the Rugby Wind Farm Substation to the existing Rugby Substation.

Rugby Wind proposes to retrofit the Facility for the purpose of improving wind turbine efficiency, increasing energy output, and prolonging the useful life of the wind farm. The retrofitting process is known as "repowering." The repower scope includes replacing the turbine nacelles and its interior elements, adding an adapter section to the tower and increasing the hub height up to 84.8 meters, replacing the rotor (hub and blades) and increasing the rotor diameter up to 120 meters, replacing generators from 2.1 MW to 2.2 MW, and reinforcing turbine foundations and associated collector lines, as needed. Rugby Wind proposes no changes to turbine locations, point of interconnection output capacity, or other existing components such as the generation-tie line and collector substation, at this time. Temporary ground disturbance is primarily limited to existing facilities such as turbine pads, electrical collection line easements, access roads, and a laydown yard.

This technical memorandum provides a shadow flicker analysis for the repowered Facility. The turbine type considered in this analysis was Vestas V120 with Serrated Trailing Edge (STE) blades.

2. What is Shadow Flicker?

Shadow flicker is the term used to refer to the alternating changes in light intensity that can occur at times when the rotating blades of wind turbines cast moving shadows on the ground or on structures. Shadow flicker occurs only when the wind turbines are operating during sunny conditions and is most likely to occur early and late in the day when the sun is at a low angle in the sky. The intensity of shadow flicker is defined as "the difference or variation in brightness at a given location in the presence or absence of a shadow" (National Research Council 2007). The intensity of the shadows cast by moving blades of wind

turbines, and thus the perceived intensity of the flickering effect, is determined by the distance of the affected area from the turbine, with the most intense, distinct, and focused shadows occurring closest to the turbine.

3. Regulatory Requirements

Pierce County granted a conditional use permit (CUP; CUP 2005-001 – Rugby Wind Farm) to Rugby Wind on July 12, 2005, and an updated CUP on September 3, 2008, prior to construction. The CUP did not include a threshold for flicker as there is no local, state, or federal zoning ordinance or permitting threshold regarding shadow flicker impact to residences from a wind energy project in Pierce County, North Dakota. For the purposes of this study, a threshold of 30 hours of shadow flicker per year at nonparticipating occupied residences has been identified consistent with prior North Dakota Public Service Commission approvals.

4. Method for Predicting Shadow Flicker Effects

Jacobs conducted the shadow flicker analysis for the proposed repowered Facility with a layout of 71 wind turbines using the SHADOW calculation module of the windPRO software. The windPRO software consists of a comprehensive package developed for the design, development, and assessment of wind farm projects, as well as for the evaluation of energy, environmental, visual, electrical, and economic effects of wind energy projects.

4.1 Turbine and Residence Locations

Figure 1 shows the locations of the wind turbines and residences included in the modeling. The primary wind turbine specifications that influence shadow flicker are the rotor diameter and hub height. Rugby Wind provided this information for 71 Vestas V120 STE turbines with rotor diameters of 120 meters and hub heights of 84.8 meters, as presented in Table 1.

Table 1. Modeled Turbine Locations

Turbine ID	Turbine Model	Rotor Diameter (m)	Hub Height (m)	Coordinates		
				X (m)	Y (m)	Z (m)
A2	V120 STE	120	84.8	423645	5377150	499
A3	V120 STE	120	84.8	423910	5377216	502
A4	V120 STE	120	84.8	424329	5377057	508
A5	V120 STE	120	84.8	424563	5377190	508
A6	V120 STE	120	84.8	424994	5377084	513
A7	V120 STE	120	84.8	425433	5376948	505
A8	V120 STE	120	84.8	428471	5376484	509
B1	V120 STE	120	84.8	429034	5375884	514
B2	V120 STE	120	84.8	429252	5376109	509
B3	V120 STE	120	84.8	429657	5376158	507
B4	V120 STE	120	84.8	430024	5376181	515
B5	V120 STE	120	84.8	428972	5375500	507

Table 1. Modeled Turbine Locations

Turbine ID	Turbine Model	Rotor Diameter (m)	Hub Height (m)	Coordinates		
				X (m)	Y (m)	Z (m)
C1	V120 STE	120	84.8	430982	5375718	516
C2	V120 STE	120	84.8	431276	5375873	519
C3	V120 STE	120	84.8	431719	5375959	513
C4	V120 STE	120	84.8	432176	5376028	507
D1	V120 STE	120	84.8	430523	5374844	515
D2	V120 STE	120	84.8	430868	5374838	509
D3	V120 STE	120	84.8	431193	5374935	516
D4	V120 STE	120	84.8	431651	5374996	514
E1	V120 STE	120	84.8	423615	5374761	494
E2	V120 STE	120	84.8	424058	5374768	494
E3	V120 STE	120	84.8	424073	5375125	487
E4	V120 STE	120	84.8	424515	5375069	492
E5	V120 STE	120	84.8	424767	5375181	480
F1	V120 STE	120	84.8	424713	5373432	509
F2	V120 STE	120	84.8	424924	5373593	507
F3	V120 STE	120	84.8	425466	5373611	501
G1	V120 STE	120	84.8	424768	5372777	494
G2	V120 STE	120	84.8	425429	5372749	491
G3	V120 STE	120	84.8	425948	5372738	494
G4	V120 STE	120	84.8	426825	5372766	501
G5	V120 STE	120	84.8	427051	5372908	507
G6	V120 STE	120	84.8	427269	5373064	504
G7	V120 STE	120	84.8	427500	5373255	489
H1	V120 STE	120	84.8	430182	5373530	514
H2	V120 STE	120	84.8	430534	5373608	521
J1	V120 STE	120	84.8	431677	5372648	508
J2	V120 STE	120	84.8	431461	5372487	519
J3	V120 STE	120	84.8	431248	5372322	513
J4	V120 STE	120	84.8	430933	5372293	504
K1	V120 STE	120	84.8	432407	5372990	522
K2	V120 STE	120	84.8	432573	5372467	513
K3	V120 STE	120	84.8	432405	5372219	513
L1	V120 STE	120	84.8	432619	5373627	519

Table 1. Modeled Turbine Locations

Turbine ID	Turbine Model	Rotor Diameter (m)	Hub Height (m)	Coordinates		
				X (m)	Y (m)	Z (m)
L2	V120 STE	120	84.8	432303	5374200	513
L3	V120 STE	120	84.8	432879	5374220	507
M1	V120 STE	120	84.8	433259	5372899	513
M2	V120 STE	120	84.8	433420	5373184	527
M3	V120 STE	120	84.8	433938	5372625	513
M4	V120 STE	120	84.8	434180	5372914	515
M5	V120 STE	120	84.8	434328	5373194	518
M6	V120 STE	120	84.8	434338	5373764	507
M7	V120 STE	120	84.8	434340	5374150	508
N1	V120 STE	120	84.8	430250	5370380	516
N2	V120 STE	120	84.8	430508	5370416	497
P1	V120 STE	120	84.8	432162	5369802	511
P2	V120 STE	120	84.8	432452	5369979	514
Q1	V120 STE	120	84.8	428730	5369235	497
Q2	V120 STE	120	84.8	428859	5369569	495
Q3	V120 STE	120	84.8	429136	5369642	497
Q4	V120 STE	120	84.8	429595	5369621	494
R1	V120 STE	120	84.8	431880	5368792	506
R2	V120 STE	120	84.8	432142	5368856	516
R3	V120 STE	120	84.8	432383	5369032	509
R4	V120 STE	120	84.8	432614	5369180	512
S1	V120 STE	120	84.8	432931	5367819	502
S2	V120 STE	120	84.8	433135	5368068	499
S3	V120 STE	120	84.8	434029	5368017	516
S4	V120 STE	120	84.8	434142	5367203	497
S5	V120 STE	120	84.8	433994	5366981	504

Notes:
ID = identifier
m = meter(s)

4.2 Shadow Flicker Modeling Parameters

As the sun approaches the horizon, sunshine becomes less intense, and, therefore, the shadow influence is reduced. To take this phenomenon into account, the standard practice in shadow flicker analysis is to calculate shadow flicker for only the times when the sun is at an angle of 3 or more degrees above the horizon. In conducting this analysis, the 3-degree threshold was observed.

Shadow flicker intensity is defined as the difference in brightness at a given location in the presence and absence of a shadow. The intensity of shadow flicker tapers off with increasing distance from the turbine. Generally, shadow flicker is most noticeable within 1,000 meters (3,274 feet) of the turbine. With increased distance from the turbine, the shadow flickering becomes less perceptible. Shadow flicker was calculated using a distance threshold defined as ten times the rotor diameter (1,200 meters or 3,937 feet). This calculated distance is where the shadow flickering would be intense enough to be detectable and a potential source of annoyance.

The orientation of each of the residences in the Facility vicinity was set on "greenhouse mode" for the model, which assumes that the residence has windows on all of its sides and, therefore, would be affected by shadow flicker that falls on any side of the structure; the "greenhouse mode" represents a worst-case scenario for each residence.

An important variable that the windPRO SHADOW calculation model considers is the probability of sunny conditions required for shadows to be present in the Facility area. To generate the data that the model requires to consider the hours of sunshine, Jacobs reviewed the meteorological data from nearby weather stations. The closest representative meteorological stations where the appropriate data are collected are located at the Devil's Lake Municipal Airport, which is approximately 51 miles southeast of the Facility location. To calculate the monthly probabilities of sunshine, hourly observations of cloud cover were obtained from the National Centers for Environmental Information (NCEI) Devil's Lake Municipal Airport meteorological monitoring station (Station ID 727573-94928).

The most recent complete[1] years of meteorological data were included in the modeling to evaluate the average sunshine probability per month. For the data at Devil's Lake Municipal Airport, the most recent complete years are 2009 through 2011 and 2013 through 2019. Year 2012 was excluded because more than 10 percent of the meteorological data were missing. The AERMET meteorological data processor was used to process the data from NCEI and calculate the monthly probabilities of sunshine. AERMET was developed by the U.S. Environmental Protection Agency to read and extract parameters from NCEI data and process meteorological data for the purposes of air dispersion modeling.

For this analysis, AERMET (Version 23132) extracted the fraction of cloud cover for each hour and calculated the convective mixing height based on the station latitude and time zone. The total daytime hours for each month were determined based on the convective mixing height, which is generated only during daytime hours. For each valid hour, cloud cover is ranked on a scale of 0 to 9 where a ranking of 0 indicates no clouds while 8 indicates completely overcast and 9 indicates sky obscured. In this analysis, a ranking of 6 and below was considered sunny by Jacobs. The total number of sunny hours (or sun hours) was divided by the total number of valid daytime hours in the month to determine each month's sunshine probability. The monthly sunshine probabilities derived through this analysis and used in calculating the Facility's adjusted or realistic shadow flicker effects are summarized in Table 2.

[1] The annual data set is considered complete if 10 percent or less of upper air station data or windspeed, wind direction, and temperature data are missing.

Table 2. Average Sunshine Probability per Month (Recorded Sun Hours/Possible Sun Hours)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.53	0.62	0.58	0.62	0.65	0.71	0.83	0.80	0.70	0.63	0.61	0.53

Based on the analysis of the available cloud cover data, the sun would be unobstructed by clouds long enough to permit shadow flicker effects to be created anywhere from 53 to 83 percent of the time during daylight hours.

Consideration of the hours of sunny versus cloudy conditions allows the model to predict the hours of shadow flicker experienced at residences. The predictions are generally accurate with respect to the actual shadow flicker conditions that would be experienced. However, these modeling results likely still represent an overestimation of total hours of shadow flicker effect. Other factors that could also affect the total amount of predicted shadow flicker, but were not taken into account in the modeling, include:

- Presence of haze or particulate matter in the air that tends to reduce the intensity of light and reduce distances at which shadows can be cast.
- Potential structures and vegetation located between residences and the turbines, which would block shadows created by the rotating turbine blades and thus prevent shadow flicker from occurring at residences.
- The model assumes that the residences are in the "greenhouse mode," in which the residence is assumed to be all windows—a worst-case scenario. Residences normally have much less window than wall space on any given side.

5. Analysis Results and Conclusion

Table 3 provides the shadow flicker modeling results for the residences evaluated. Figure 1 provides a graphical representation of the patterns of total annual shadow flicker exposure around each of the wind turbines and the proximity of each residence to these patterns. The predicted number of hours and minutes of shadow flicker on an annual basis have been adjusted to reflect cloud cover conditions, providing a more realistic estimate of potential shadow flicker exposure.

Table 3. Summary of Predicted Shadow Flicker Exposure at Residences in the Facility Area

Residence Status[a]	Residence ID	Coordinates		Total Predicted Annual Shadow Flicker Exposure (hrs:min per year)[b]
		X (m)	Y (m)	
Participating	REC13	429213	5370074	53:36
Nonparticipating	REC04	425106	5377692	20:42
Participating	REC10	427444	5372591	20:50
Participating	REC19	433357	5367173	22:02
Participating	REC14	431323	5368466	18:23
Participating	REC39	423186	5375339	23:09
Participating	REC07	425672	5375293	7:42
Participating	REC34	423800	5375837	11:31
Participating	REC18	432920	5367309	4:02
Participating	REC35	423578	5373574	4:17
Nonparticipating	REC62	434301	5363345	0:00

Table 3. Summary of Predicted Shadow Flicker Exposure at Residences in the Facility Area

Residence Status[a]	Residence ID	Coordinates		Total Predicted Annual Shadow Flicker Exposure (hrs:min per year)[b]
		X (m)	Y (m)	
Nonparticipating	REC32	433061	5362491	0:00
Participating	REC33	423661	5376293	0:00
Nonparticipating	REC15	432989	5371214	0:00
Participating	REC08	433360	5375223	0:00
Participating	REC44	426194	5376303	0:00
Nonparticipating	REC12	426634	5371313	0:00
Nonparticipating	REC06	428370	5377614	0:00
Nonparticipating	REC59	422487	5375868	0:00
Participating	REC23	435372	5374993	0:00
Participating	REC11	425699	5370908	0:00
Participating	REC20	433138	5365907	0:00
Nonparticipating	REC38	423222	5372146	0:00
Nonparticipating	REC58	422113	5375952	0:00
Nonparticipating	REC30	434641	5365645	0:00
Nonparticipating	REC16	431215	5366507	0:00
Nonparticipating	REC57	421887	5374243	0:00
Nonparticipating	REC25	436397	5372533	0:00
Nonparticipating	REC55	422545	5372689	0:00
Participating	REC60	429848	5366794	0:00
Nonparticipating	REC36	423463	5371000	0:00
Participating	REC27	436154	5368809	0:00
Nonparticipating	REC56	421745	5373378	0:00
Nonparticipating	REC05	427876	5379003	0:00
Participating	REC17	426580	5368203	0:00
Nonparticipating	REC37	424736	5369835	0:00
Nonparticipating	REC63	437098	5372305	0:00
Nonparticipating	REC03	425070	5379856	0:00
Nonparticipating	REC47	422614	5371019	0:00
Nonparticipating	REC28	436117	5365894	0:00
Nonparticipating	REC02	425012	5380574	0:00
Nonparticipating	REC01	423459	5380440	0:00
Nonparticipating	REC48	421813	5370887	0:00
Nonparticipating	REC52	437832	5375630	0:00

Table 3. Summary of Predicted Shadow Flicker Exposure at Residences in the Facility Area

Residence Status[a]	Residence ID	Coordinates		Total Predicted Annual Shadow Flicker Exposure (hrs:min per year)[b]
		X (m)	Y (m)	
Nonparticipating	REC50	432868	5363892	0:00
Nonparticipating	REC22	428923	5364470	0:00
Nonparticipating	REC49	421929	5369060	0:00
Nonparticipating	REC61	429637	5363884	0:00
Nonparticipating	REC31	436215	5363795	0:00
Nonparticipating	REC51	437078	5364423	0:00
Nonparticipating	REC29	437713	5365035	0:00
Nonparticipating	REC41	424801	5366011	0:00
Nonparticipating	REC40	422998	5367053	0:00
Nonparticipating	REC21	427132	5363714	0:00
Nonparticipating	REC42	423349	5365751	0:00
Nonparticipating	REC43	423335	5364105	0:00
Nonparticipating	REC46	422508	5364580	0:00

[a] For purposes of this memorandum, a participating landowner is a landowner that has signed a wind option, easement agreement, or waiver with Rugby Wind, LLC.

[b] Results do not account for the screening effect of nearby vegetation or orientation of windows.

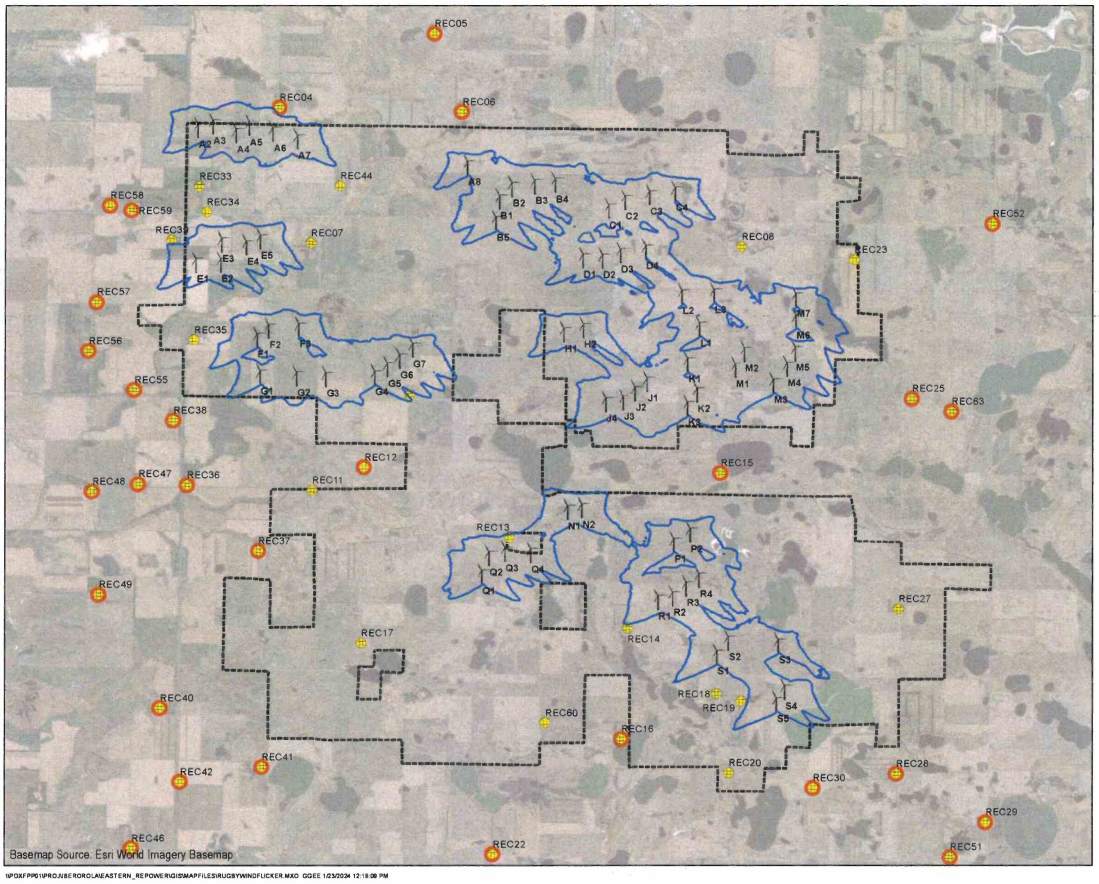
Note: hrs:min = hours:minutes

Participating residence REC13 is the only residence located in an area where the 30-hour-per-year threshold of expected annual shadow flicker exposure is predicted to be exceeded. The total predicted annual shadow flicker at REC13 is 53 hours, 36 minutes per year with the majority of the potential shadow flicker predicted to occur between November and January during mid-morning and early afternoon hours. Attachment 1 provides a graphical calendar that illustrates the periods of potential shadow flicker at REC13. No nonparticipating residence is predicted to exceed the shadow flicker threshold of 30 hours per year.

6. Reference

National Research Council. 2007. *Environmental Impacts of Wind-Energy Projects.* National Academies Press.

Figure



LEGEND

- Annual Hours of Shadow Flicker (30 hours)
- Rugby Wind Turbine
- Residence
- Nonparticipating Residence
- Facility Site Boundary

Note:
STE = Serrated Trailing Edge

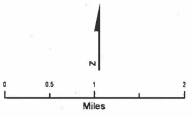


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Figure 1
Predicted Shadow Flicker
Vestas V120 Repower STE Blades
Rugby Wind Repower Project

Jacobs

Attachment 1
Graphical Calendar of Potential Shadow Flicker at Participating Residence REC13

Attachment 1
Graphical Calendar of Potential Shadow Flicker at Participating Residence REC13