Shadow Flicker Study
Desert Claim Wind Project

1 Introduction

In 2010, the State of Washington and Desert Claim Wind Power LLC (Desert Claim) entered into a Site Certification Agreement authorizing the construction and operation of a 95-turbine 190 megawatt (MW) wind power project in central Washington, near Ellensberg. Desert Claim is now requesting an amendment to the Site Certification Agreement to authorize construction and operation of a smaller project, with no more than 31 turbines and a maximum capacity of 100 MW. This shadow flicker analysis was undertaken because the proposed number, type and location of turbines will be different than authorized by the 2010 Site Certification Agreement.

The potential for shadow flicker was modeled using an industry-standard computer model, employing conservative assumptions. The modeling indicated that most nearby residences would experience little or no shadow flicker, and only four residences had the potential of experiencing more than 30 hours per year of shadow flicker under worst case modeling assumptions. If, in fact, these residences experience annoying shadow flicker, Desert Claim proposes to work with EFSEC to implement appropriate mitigation measures.

2 Shadow Flicker

Shadow flicker is described as “alternating changes in light intensity” that can occur when wind turbines blades rotate and cast shadows.[1] The flickering effect can occur inside buildings when the shadow passes across a relatively narrow window opening, but the extent varies depending upon the position of the sun, the degree of sunshine versus cloudiness, the speed at which the turbine blades are rotating, and the position of the receptor.[2]

Shadow flicker, if it occurs at all, becomes less noticeable as the distance between the wind turbines and receptors increase. The report from DNV Global Energy Concepts submitted with Desert Claim’s 2009 application explained that “Shadows become less sharp (more diffuse) as the distance between the shadow-casting object and the observer grows. When considering shadows cast by relatively small objects at a long distance from the observer, at a sufficient distance no noticeable shadow forms at all because the object does not significantly block the sun's light. Instead, light diffracts (or bends) around the edges of the object, and the object itself becomes relatively small compared to the apparent size of the sun. The object becomes something that is silhouetted in front of the sun rather than something casting a shadow.”[3]

3 Modeling Methods

The potential for shadow flicker was modeled using a computer software package from Openwind. The Openwind user manual explains that "[s]hadow flicker is modelled using freely available NREL solar declination code to calculate the sun vector minute-by-minute over the course of a year." In simpler terms, Openwind is able to estimate the number of minutes that shadow flicker could be experienced at receptor locations on a daily and yearly basis if given the following inputs: receptors locations, turbines locations, the topography, the site time zone and site specific sunshine data expressed whether as total sunshine hours per month, daily sunshine hours per month or sunshine probability (%) per month.

Like other shadow flicker modeling software, Openwind does not take into account turbine orientation, turbine availability, and the location of residential windows. In other words, the modeling includes several very conservative assumptions.

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[1] Thomas Priestley, An Introduction to Shadow Flicker and its Analysis, available at http://windharvest.com/wp-content/uploads/2017/03/Shadow-Flicker.pdf

[2] Parsons Brinckerhoff, Update of UK Shadow Flicker Evidence Base, report prepared for the U.K. Department of Energy and Climate Change and available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48052/1416-update-uk-shadow-flicker-evidence-base.pdf

[3] Global Energy Concepts, Shadow Mapping for the Desert Claim Project (Dec. 19, 2008).

The model assumes that turbines are always facing the direction that would result in the maximum shadow flicker effect. In fact, the wind turbines rotate to face the direction from which the wind is blowing.

The model also assumes that turbines are operating during all daylight hours. If a turbine's rotors are not turning, either due to insufficient wind or other operational issues, there would be no shadow flicker. Given wind conditions at the location, turbines are expected to operate approximately 60 percent of the time at Desert Claim.

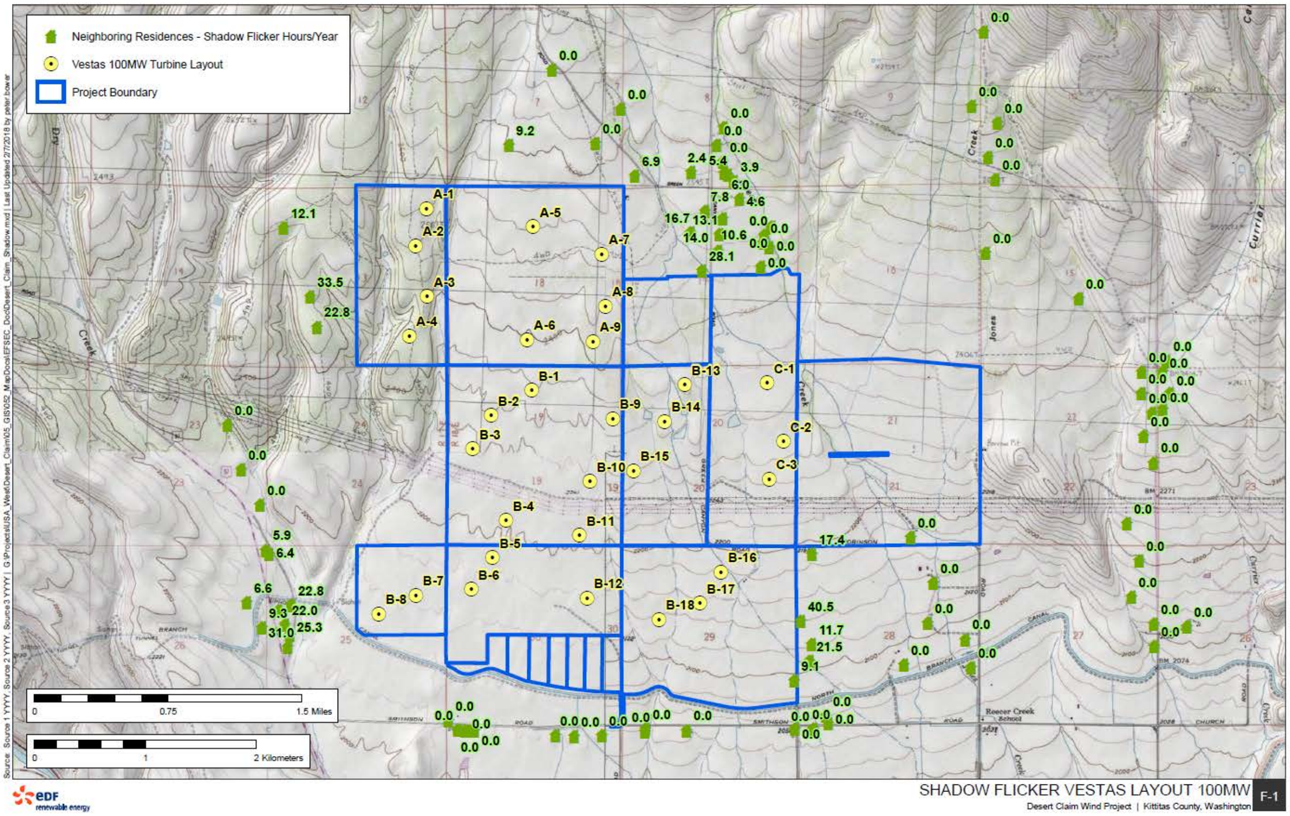
The model also assumes that sunlight reaches the windows of the residential receptor being modeled without obstruction. If trees, bushes or other structures block sun from reaching the window, or if windows are not located where the potential shadow flicker is modeled, people inside the residence will not experience any shadow flicker.

Shadow flicker modeling for the Desert Claim project was performed to evaluate the potential for shadow flicker at 88 residences in the vicinity of the project. The location of the residences is shown on **Figures 1** and **2.**

The modeling considered two possible configurations for the revised project. The first configuration utilized a maximum of 31 Vestas turbines for a total capacity of 100 MW. This configuration includes five Vestas V110 turbines, which have a hub height of 80 m and a rotor diameter of 110 m, and twenty-five Vestas 136 turbines, which have a hub height of 82 m and a rotor diameter of 136 m. The location of these turbines relative to modeled residential receptors is shown on **Figure 1**.

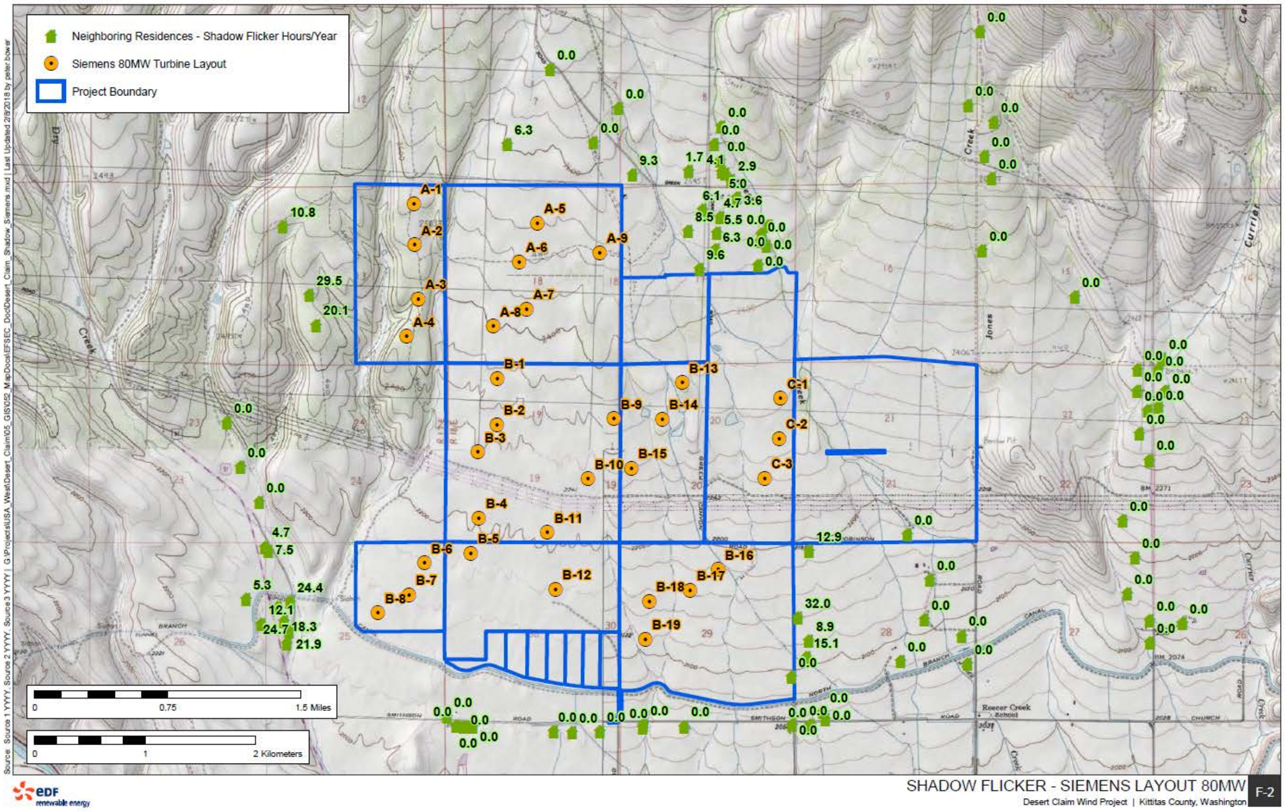
The second configuration utilized a maximum of 25 Siemens turbines for a total capacity of 80 MW. This configuration includes four Siemens SWT 108 turbines, which have a hub height of 80 m and a rotor diameter of 108 m, and twenty-seven Siemens SWT 120 turbines, which have a hub height of 85.1 m and a rotor diameter of 120 m. All turbines are located at least 2500 feet from residences. The location of these turbines relative to modeled residential receptors is shown on **Figure 2**.

Figure 1



Neighboring Residences - Shadow Flicker Hours/Year
Vestas 100MW Turbine Layout
Project Boundary
0
0.75
1.5 Miles
0
1
2 Kilometers
SHADOW FLICKER VESTAS LAYOUT 100MW
Desert Claim Wind Project | Kittitas County, Washington
F-1

Figure 2



4 Results

Modeling was performed to indicate the potential for shadow flicker at 88 residential receptors in the vicinity of the project. At each receptor, the modeling indicated the total number of hours per year in which shadow flicker might occur, and the maximum potential minutes of shadow flicker in a single day.

For the Vestas configuration, the modeling indicated that shadow flicker could occur at 30 of the 88 residential receptors modeled. For those residences, the potential total annual duration of shadow flicker ranged from 2.4 to 40.5 hours, with only three residences having the potential to experience more than 30 hours per year. The maximum possible minutes of shadow flicker in a day at these residences ranged from 22 to 50 minutes.

Detailed results of the modeling for the Vestas turbine configuration are provided in **Table 1**.

Table 1: Modeling Results – Vestas Configuration

Receptor	Hours/Year	Maximum Minutes/Day
1	0	0
2	0.0	0
3	40.5	40
4	0.0	0
5	14.0	30
6	17.4	38
7	0.0	0
8	0.0	0
9	0.0	0
10	28.1	35
11	0.0	0
12	0.0	0
13	0.0	0
14	0.0	0
15	0.0	0
16	0.0	0
17	0.0	0
18	0.0	0
19	0.0	0
20	0.0	0
21	0.0	0
22	0.0	0
23	0.0	0
24	16.7	38
25	13.1	30
26	21.5	30
27	0.0	0
28	11.7	30
29	0	0
30	0	0
31	0	0
32	0	0
33	31	44
34	25	50
35	22	50
36	23	47

37	6	28
38	0	0
39	9	37
40	0	0
41	0	0
42	33	34
43	0	0
44	0	0
45	6	28
46	0	0
47	23	38
48	0	0
49	0	0
50	0	0
51	0	0
52	0	0
53	9	25
54	7	32
55	2	22
56	8	32
57	11	28
58	5	24
59	6	26
60	5	25
61	4	23
62	0	0
63	0	0
64	0	0
65	0	0
66	0	0
67	0	0
68	0	0
69	0	0
70	0	0
71	0	0
72	0	0
73	0	0
74	0	0
75	0	0
76	0	0

77	0	0
78	0	0
79	0	0
80	19	46
81	7	27
82	9	30
83	12	27
84	0	0
85	0	0
86	0	0
87	0	0
88	0	0

For the Siemens configuration, the modeling indicated that shadow flicker could occur at 29 of the 88 residential receptors. For those residences, the potential total annual duration of shadow flicker ranged from 1.7 to 32.1 hours, with only one residence having the potential to experience more than 30 hours per year. The maximum possible minutes of shadow flicker in a day at these residences ranged from 18 to 48 minutes.

The detailed results of the modeling for the Siemens turbine configuration are provided in **Table 2.**

Receptor	Hours/Year	Maximum Minutes/Day
1	0	0.00
2	0	0.00
3	32.1	35.00
4	0	0.00
5	6.3	26.00
6	12.9	33.00
7	0	0.00
8	0	0.00
9	0	0.00
10	9.6	30.00
11	0	0.00
12	0	0.00
13	0	0.00
14	0	0.00
15	0	0.00
16	0	0.00
17	0	0.00
18	0	0.00
19	0	0.00

20	0	0.00
21	0	0.00
22	0	0.00
23	0	0.00
24	8.5	34.00
25	5.5	26.00
26	15.1	25.00
27	0	0.00
28	8.9	25.00
29	0	0.00
30	0	0.00
31	0	0.00
32	0	0.00
33	24.7	44.00
34	21.9	48.00
35	18.3	48.00
36	24.4	34.00
37	7.5	24.00
38	0	0.00
39	6.4	30.00
40	0	0.00
41	0	0.00
42	29.5	30.00
43	0	0.00
44	0	0.00
45	4.7	25.00
46	0	0.00
47	20.1	34.00
48	0	0.00
49	0	0.00
50	0	0.00
51	0	0.00
52	0	0.00
53	0	0.00
54	9.3	30.00
55	1.7	18.00
56	6.1	28.00
57	4.7	25.00
58	3.7	21.00
59	5.0	23.00

60	4.1	22.00
61	2.9	22.00
62	0	0.00
63	0	0.00
64	0	0.00
65	0	0.00
66	0	0.00
67	0	0.00
68	0	0.00
69	0	0.00
70	0	0.00
71	0	0.00
72	0	0.00
73	0	0.00
74	0	0.00
75	0	0.00
76	0	0.00
77	0	0.00
78	0	0.00
79	0	0.00
80	14.6	34.00
81	5.3	24.00
82	12.1	38.00
83	10.8	24.00
84	0	0.00
85	0	0.00
86	0	0.00
87	0	0.00
88	0	0.00

5 Conclusion

Although all turbines under the proposed configurations are located more than 2,500 feet from residences, it is possible that some residences may experience brief periods of shadow flicker during certain atmospheric conditions. If nearby residences experience annoyance from shadow flicker, Desert Claim will work with EFSEC and the residents to implement measures that will avoid, minimize, and mitigate shadow flicker. Shadow flicker can usually be satisfactorily addressed by planting trees, shading windows or other mitigation measures. As a last resort, the control system of a wind turbine could be programmed to stop the blades from turning during the brief periods when conditions result in perceptible shadow flicker.

6 Author Bios

Jared Kassebaum is Manager of the Energy Team at EDF Renewable Energy. He has a Ph.D. in Mechanical and Aerospace Engineering from the University of Virginia, and a B.S. in Engineering Science and Applied Mathematics from Northwestern University. Jared has 9 years of experience modeling shadow flicker effects from wind energy projects.

Eric Jeannotte is a Senior Wind Analyst for EDF EN Canada Inc. He has a Master's Degree in Engineering – Renewable Energy from Quebec University, and a Bachelor's Degree in Mechanical Engineering from McGill University. Eric has 5 years of experience modeling shadow flicker effects from wind energy projects.