Appendix D

Foundation Evaluation Report

Community Wind South Repower Project
Nobles County, Minnesota

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Maple Grove, MN 55369
612.225.1240

May 21, 2021
Via email: justin.fike@greenbackercapital.com

Justin Fike
Greenbacker Renewable Energy Corporation
11 East 44th Street, Suite 1200
New York, NY 10017

Re: Uprate Evaluation of Existing 58'-6" Wind Turbine Foundations
Community Wind South Wind Project – Nobles County, Minnesota
RRC Project No.: SE2011030

Dear Mr. Fike,

This letter is written to present the results of evaluating the existing REpower MM92 100m HH IEC IIA (REpower) 58'-6" wind turbine foundations on the Community Wind South Wind Project located in Nobles County, Minnesota based on new loads provided by Vestas for Vestas V110 2.2MW Mk10D IEC S 105.05m 60 Hz VCS (V110) wind turbines. The turbine extreme loads, operational "no uplift" loads, and fatigue loads are different than the original REpower loads, so design checks were completed based on the new loads.

Project Background

The original foundation design was created by RRC (formerly known as Renewable Resource Consultants) in 2012 assuming that up to 15 turbines would be constructed using the REpower turbines. Two octagonal, spread foundation designs were created with 58'-6" and 63'-6" diameters, respectively. The wind turbine towers utilized a foundation mounting piece (FMP) embedded into the foundation designed by others. The turbine foundations were constructed with REpower turbines and the drawings were issued for construction on May 11, 2012. As-built foundation drawings were issued on September 18, 2012.

Analysis

REpower originally provided both load spectra and Markov fatigue loads for 20 years of operation under the REpower loads. Markov fatigue loads are considered industry standard and will be utilized for this uprate analysis. Vestas provided site-specific loads for the V110 turbine as well as fatigue loads for 20 years of operation after the uprate. These loads were used to perform all the design checks according to current industry standards using the existing REpower 58'-6" foundation design. The FMP is considered part of the tower design and is not included in the scope of the foundation uprate analysis. This letter evaluates only the 58'-6" foundation design although the 63'-6" foundation design will be evaluated separately.

Results

The extreme loads control the design of most of the foundation structural components while the operational "no uplift" loads are loads under which the foundation must maintain 100% contact with the subgrade for certain geotechnical conditions. A comparison of the extreme and operational "no uplift" loads between the original REpower loads and the uprated V110 loads is shown below:

REpower vs. V110 Turbine Loads							
	Extreme Overturning Loads				"No Uplift" Loads		
	REpower	V110			REpower	V110	
Controlling Load Case	DLC 2.2a	fam54			DLC 1.2	DLC 1.0	
Axial Load	686.6 kips	694.4 kips	1.14%		696.7kips	695.5 kips	-0.17%
Shear Load	175.8 kips	108.9 kips	-38.05%		58.9 kips	84.7 kips	43.80%
Overturning Moment	56,721 k-ft	37,704 k-ft	-33.53%		25,753 k-ft	29,175 k-ft	13.29%
Factored Overturning Moment	62,393 k-ft	50,901 k-ft	-18.42%		25,753 k-ft	29,175 k-ft	13.29%

As can be seen in the table above, the extreme loads for the V110 turbines decreased from the original REpower loads. The operational "no uplift" loads increased, however, uplift does not occur under the V110 "no uplift" loads. **As a result, the extreme load checks from the existing foundation design pass using the new V110 loads.** See below for a summary of the design checks.

V110 Analysis Design Results			
Design Check Performed	**Design Requirement/ Capacity**	**Uprate Results**	**Result**
Extreme Bearing Check	3,500 psf	1,530 psf	Pass
Factor of Safety to Sliding Check	1.5	4.75	Pass
Foundation Gapping Under "No Uplift" Loads	No Gapping	No Gapping	Pass
Minimum Horizontal Stiffness	7 kN/mm	3,187 kN/mm	Pass
Minimum Rotational Stiffness	2.40E7 kN-m/rad	2.24E8 kN-m/rad	Pass
Stability Check – Factor of Safety to Overturning for Combined tower/turbine/foundation	1.67	3.60	Pass
Base Reinforcement Design	See Note 1		Pass
Base One-Way Shear Check	See Note 2		Pass
Pedestal Skin Reinforcement Design Check	0.683 in^2/ft	0.704 in^2/ft	Pass
Base FMP Pull-Out Design Check	< 1.0	0.59	Pass
Base FMP Punching Shear Design Check	< 1.0	0.43	Pass
Base FMP Bursting Stress Design Check	0.346 in^2/stirrup	0.44 in^2/stirrup	Pass

1. The base flexural reinforcement passes as currently designed.
2. Bottom and top steel one-way shear checks pass as currently designed.

The fatigue analysis is based on Markov fatigue loads provided by REpower and Vestas. The REpower fatigue loads were adjusted to account for 10 years of existing turbine operation and Vestas provided fatigue loads for 20 years of additional operation of the V110 turbine. The REpower and Vestas Markov loads are comprised of hundreds of load cases and associated occurrence cycles. The fatigue analysis is performed by calculating an equivalent damage ratio for various components of the foundation which is calculated by summing the calculated number of design life cycles (N) by the associated occurrence cycles (n) for each of the load cases provided in the load spectra or Markov data. RRC uses the methods described in the DNVGL-ST-C502 August 2017 edition document to perform the fatigue checks, which is an updated version compared to what was available when the original REpower foundations were designed. Fatigue standards have become more stringent as the wind industry has matured over the years and typically govern several foundation design components.

For concrete that can be inspected and repaired, a fatigue check is considered passing if the equivalent damage ratio is less than 1.0. For reinforcement, a fatigue check is conservatively considered to be passing if the equivalent damage ratio is less than 0.33 (when the reinforcement component is not able to be inspected or repaired, as in the case with these wind turbine foundations). Note that at the time of the foundation design, it was industry standard to use an equivalent damage ratio less than 0.5 for reinforcement that could not be inspected. The damage ratios shown below are for the complete 10-year operation of the REpower turbines plus 20 years of additional V110 operation. A summary of the results of the fatigue design checks is shown in the following table:

Fatigue Analysis Design Results		
Design Check Performed	**Calculation**	**Result**
Base Flexural Concrete Compression (Uplift Side)	**0.000**	Pass
Base Flexural Concrete Compression (Bearing Side)	**0.000**	Pass
Base Flexural Reinforcement Tension (Uplift Side)	**0.051**	Pass
Base Flexural Reinforcement Tension (Bearing Side)	**0.000**	Pass
Base Flexural Reinforcement Tension (Uplift Side @ Bend)	**0.029**	Pass
Base Flexural Reinforcement Tension (Uplift Side @ Cut Off)	**0.000**	Pass
Base Pull-Out Cone Above Embedment Ring (Concrete)	**0.002**	Pass
Base Pull-Out Cone Above Embedment Ring (Reinforcement)	**0.008**	Pass
Base Pull-Out Cone Above Embedment Ring (Reinforcement Bond)	**0.000**	Pass
Base One-Way Shear (Uplift Side)	**0.000**	Pass
Base One-Way Shear (Bearing Side)	**0.000**	Pass
Base Concrete Bearing	**0.000**	Pass

As can be seen above, all fatigue checks pass and are acceptable.

Conclusions

All the design checks pass using the new Vestas V110 turbine loads. Therefore, the existing 58'-6" foundation design on the Community Wind South Wind Project is suitable for the V110 turbine. RRC recommends performing visual inspections of the foundation pedestals prior to uprating turbines to confirm there are no indications of soil movement or concrete damage.

Note that while this analysis has a favorable conclusion to allow the turbines to be uprated, this analysis is not considered a construction engineering document. Updated stamped engineering design calculations and drawings must be completed and issued prior to uprating any turbines.

Please contact our office with any questions you may have.

Sincerely,
RRC Power & Energy, LLC

JASON D. STRIPLING
LICENSED PROFESSIONAL ENGINEER
51768
STATE OF MINNESOTA
05/21/2021

Jason Stripling, PE (MN)
Sr. Structural Engineer

References:

1. "Community Wind South Wind Project As-Built Foundation Design Drawings" from Renewable Resource Consultants, LLC dated September 18, 2012, Rev. 5.
2. "Signal Energy, LLC, Community Wind South Wind Project, Foundation Design for REpower MM92 100M HH IEC 2a Wind Turbine, Nobles County, Minnesota" from Renewable Resource Consultants, LLC dated April 24, 2012, Project Number: 120055, Rev. 1.
3. "Foundation Loads, V110-2.2 MW, Mk10D, IEC S, 105.05m, 60 Hz, VCS, Community Wind South Wind Farm, Minnesota USA" from Vestas Wind Systems A/S dated May 11, 2021, Rev. 01, Document: 0100-7465 VER 01.
    a. Fatigue Data: 0100-7465-V01 – Appendix B – Foundation fatigue spectra.xlsx
4. "Wind Energy Converter, Repower MM92, Cold Climate S-Class (CCV) based on IEC IIA (Ed. 3) with Tower Control, Specification for Foundation Design, Tower with 98-100m Hub Height, Rotor Blade LM45.3p" from REpower Systems Dated November 25, 2011, Rev. A.
    a. Fatigue Data: C-2 12-RT 00 07-A-A.xls
5. "Foundation Insert Section General Notes and Details, Repower MM92 2.050MW IEC CCV S Based on IEC2A ED 3 + TwC 98m-100m 4 Section Tower" from Agbayani Structural Engineering dated January 3, 2012, Document No. Z-2.20-RT.01.02-A-A-EN, Sheets S2.0 and S2.1.

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May 21, 2021
Via email: justin.fike@greenbackercapital.com

Justin Fike
Greenbacker Renewable Energy Corporation
11 East 44th Street, Suite 1200
New York, NY 10017

Re: Uprate Evaluation of Existing 63'-6" Wind Turbine Foundations
Community Wind South Wind Project – Nobles County, Minnesota
RRC Project No.: SE2011030

Dear Mr. Fike,

This letter is written to present the results of evaluating the existing REpower MM92 100m HH IEC IIA (REpower) 63'-6" wind turbine foundations on the Community Wind South Wind Project located in Nobles County, Minnesota based on new loads provided by Vestas for Vestas V110 2.2MW Mk10D IEC S 105.05m 60 Hz VCS (V110) wind turbines. The turbine extreme loads, operational "no uplift" loads, and fatigue loads are different than the original REpower loads, so design checks were completed based on the new loads.

Project Background

The original foundation design was created by RRC (formerly known as Renewable Resource Consultants) in 2012 assuming that up to 15 turbines would be constructed using the REpower turbines. Two octagonal, spread foundation designs were created with 58'-6" and 63'-6" diameters, respectively. The 63'-6" diameter foundation was utilized at three locations: T-3, T-6 and T-9. The wind turbine towers utilized a foundation mounting piece (FMP) embedded into the foundation designed by others. The turbine foundations were constructed with REpower turbines and the drawings were issued for construction on May 11, 2012. As-built foundation drawings were issued on September 18, 2012.

Analysis

REpower originally provided both load spectra and Markov fatigue loads for 20 years of operation under the REpower loads. Markov fatigue loads are considered industry standard and will be utilized for this uprate analysis. Vestas provided site-specific loads for the V110 turbine as well as fatigue loads for 20 years of operation after the uprate. These loads were used to perform all the design checks according to current industry standards using the existing REpower 63'-6" foundation design. The FMP is considered part of the tower design and is not included in the scope of the foundation uprate analysis. This letter evaluates only the 63'-6" foundation design although the 58'-6" foundation design will be evaluated separately.

Results

The extreme loads control the design of most of the foundation structural components while the operational "no uplift" loads are loads under which the foundation must maintain 100% contact with the subgrade for certain geotechnical conditions. A comparison of the extreme and operational "no uplift" loads between the original REpower loads and the uprated V110 loads is shown below:

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Axial Load	686.6 kips	694.4 kips	1.14%		696.7kips	695.5 kips	-0.17%
Shear Load	175.8 kips	108.9 kips	-38.05%		58.9 kips	84.7 kips	43.80%
Overturning Moment	56,721 k-ft	37,704 k-ft	-33.53%		25,753 k-ft	29,175 k-ft	13.29%
Factored Overturning Moment	62,393 k-ft	50,901 k-ft	-18.42%		25,753 k-ft	29,175 k-ft	13.29%

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V110 Analysis Design Results			
Design Check Performed	**Design Requirement/ Capacity**	**Uprate Results**	**Result**
Extreme Bearing Check	2,500 psf	1,280 psf	Pass
Factor of Safety to Sliding Check	1.5	5.85	Pass
Foundation Gapping Under "No Uplift" Loads	No Gapping	No Gapping	Pass
Minimum Horizontal Stiffness	7 kN/mm	3,693 kN/mm	Pass
Minimum Rotational Stiffness	2.40E7 kN-m/rad	2.96E8 kN-m/rad	Pass
Stability Check – Factor of Safety to Overturning for Combined tower/turbine/foundation	1.67	4.45	Pass
Base Reinforcement Design	See Note 1		Pass
Base One-Way Shear Check	See Note 2		Pass
Pedestal Skin Reinforcement Design Check	0.683 in^2/ft	0.704 in^2/ft	Pass
Base FMP Pull-Out Design Check	< 1.0	0.59	Pass
Base FMP Punching Shear Design Check	< 1.0	0.43	Pass
Base FMP Bursting Stress Design Check	0.346 in^2/stirrup	0.44 in^2/stirrup	Pass

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Fatigue Analysis Design Results		
Design Check Performed	**Calculation**	**Result**
Base Flexural Concrete Compression (Uplift Side)	**0.000**	Pass
Base Flexural Concrete Compression (Bearing Side)	**0.000**	Pass
Base Flexural Reinforcement Tension (Uplift Side)	**0.057**	Pass
Base Flexural Reinforcement Tension (Bearing Side)	**0.001**	Pass
Base Flexural Reinforcement Tension (Uplift Side @ Bend)	**0.024**	Pass
Base Flexural Reinforcement Tension (Uplift Side @ Cut Off)	**0.000**	Pass
Base Pull-Out Cone Above Embedment Ring (Concrete)	**0.002**	Pass
Base Pull-Out Cone Above Embedment Ring (Reinforcement)	**0.008**	Pass
Base Pull-Out Cone Above Embedment Ring (Reinforcement Bond)	**0.000**	Pass
Base One-Way Shear (Uplift Side)	**0.000**	Pass
Base One-Way Shear (Bearing Side)	**0.000**	Pass
Base Concrete Bearing	**0.000**	Pass

As can be seen above, all fatigue checks pass and are acceptable.

Conclusions

All the design checks pass using the new Vestas V110 turbine loads. Therefore, the existing 63’-6” foundation design on the Community Wind South Wind Project is suitable for the V110 turbine. RRC recommends performing visual inspections of the foundation pedestals prior to uprating turbines to confirm there are no indications of soil movement or concrete damage.

Note this analysis is not considered a construction engineering document. Updated stamped engineering design calculations and drawings would need to be completed and issued prior to uprating any turbines or performing any structural changes to the foundations.

Please contact our office with any questions you may have.

Sincerely,
RRC Power & Energy, LLC

JASON D. STRIPLING
LICENSED PROFESSIONAL ENGINEER
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05/21/2021

Jason Stripling, PE (MN)
Sr. Structural Engineer

References:

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