TECHNICAL NOTE

Desert Claim Wind Project - Hazard Report

EDF Renewable Development, Inc.

Document No.: 10014039-HOU-T-01
Date: 2 February 2018

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Project name:	Desert Claim Wind Farm	DNV GL Energy
Report title:	Desert Claim Project Hazard Report	Renewables Advisory
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Project No.:	10014039	
Document No.:	10014039-HOU-T-01	

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1 INTRODUCTION

This report is issued to EDF Renewable Development, Inc. (the "Client") pursuant to DNV GL Work Orders 124011-01-A dated 11 December 2015 and 124011-02-A dated 12 December 2017, addendums to Master Services Agreement 702202/AP/01 between DNV GL and EDF Renewable Development, Inc. and is subject to the terms and conditions contained therein.

The Client has requested that Garrad Hassan America, Inc. (DNV GL) provide a preliminary evaluation of the risks for tower collapse, blade failure and ice shedding for onshore wind farms based on technical literature and DNV GL's experience, and provide an opinion about the adequacy of the proposed Project setbacks. Site-specific quantitative modelling for the Desert Claim Wind Project was not undertaken; however, the preliminary wind farm layout, setbacks and the various technology options for the Project were broadly considered. The technology options consist of four possible models:

- Vestas V110 at 80m hub height;
- Vestas V136 at 82m hub height;
- Siemens with a 108m rotor diameter and 80m hub height;
- Siemens with a 120m rotor diameter and 85m hub height.

2 TOWER COLLAPSE AND BLADE FAILURE

In 2014, Faasen et al. [1] published an update to the Handboek Risicozonering Windturbines ("Dutch Handbook") on wind turbine failure risk assessment, for the Netherlands Government. The Handbook was originally published in 2000, with a previous update in 2005 as new data became available. The 2014 Edition of the Handbook is regarded as the most recent comprehensive and independent review of wind turbine failure rates, with the aim of conducting safety risk assessments. The overall purpose of the Handbook was to provide a framework for siting wind turbines with emphasis on estimating the probability of tower collapse and flying debris.

Similarly, in 2013, the Health and Safety Executive (HSE) of the UK, in collaboration with the US National Renewable Energy Laboratory (NREL), published a framework and methodology for the estimation of risk and harm to persons from wind turbine failures [2]. The study reviewed failure rates provided by various sources, including failure rates included in the 2005 Edition of the Dutch Handbook [3].

In North America, the most recent comprehensive publication was prepared for the California Energy Commission, by Larwood et al. in 2006 [4], The study reviewed setback requirements is Counties with wind energy development experience and provided an overview of published failure rates. It included, once again, the failure rates developed under the 2005 Edition of the Dutch Handbook which were in general agreement with other sources of data.

To evaluate the risk or likelihood of injury due to wind turbine tower collapse or blade flying debris, the following items must be considered collectively: (i) the probability of a failure, (ii) the probability of a tower collapse or a blade or part of a blade detaching from the turbine as a result of the failure, and (iii) the probability of a person being present where the detached part impacts the ground. Taken individually, the probability of each of these events is very low. Taken together, the probability of all of them occurring simultaneously is extremely remote. As a matter of fact, at the time of this report and with over 300,000 wind turbines operating worldwide, DNV GL is not aware of any injuries to the public from a wind turbine tower collapse or blade debris.

2.1 Tower Collapse

As stated in the UK HSE publication [2], tower collapse is a very rare event for modern wind turbines. Possible causes of tower collapse include inadequate fastening of the tower sections or bolt anchors, due to under-designed foundations or tower buckling under extreme load events.

In 2014, the Dutch Handbook estimated the expected risk of tower collapse to be 0.000058 turbines per year or, equivalently, 1 in 17,000 years for any given turbine.

The Dutch Handbook estimated that the impact zone of a tower collapse is limited to the immediate vicinity of the turbine base within a distance equal to the hub height plus blade length. For the turbine models under consideration at Desert Claim, this would result in an impacted area ranging from 134 m to 150 m from the wind turbine. However, as stated above, the likelihood of a tower collapse is rare, and the presence of human activity during a tower collapse is extremely remote.

2.2 Blade Failure

Blade failure events are also rare, and blade separation (in whole or in part) is rarer, due to improvements in blade technology and turbine certification.

In the 2014 Dutch Handbook, the risk of blade failure was estimated to be 0.00063 turbines per year or equivalently 1 in 1,600 years for any given turbine. This failure rate was derived for situations where a blade fragment becomes detached from the main structure causing an inherent risk to people or nearby infrastructure, as opposed to a failure where no parts are ejected from the turbine but there is a loss of energy production. Per the Dutch Handbook, the overall blade failure rate has declined by a factor of three since the early 1990s.

Taking a conservative approach, the 2014 Dutch Handbook maintained the same recommended blade failure rates as the 2005 version, due in part to a lack of a comprehensive worldwide database. However, the updated 2014 Dutch Handbook noted a continued downward trend in the occurrence of blade failure over the last ten years of data that it considered (2001-2010). A 5-year rolling average under one consulted source, which is more indicative of current technology, decreased to slightly over 0.0002 turbines per year. This is equivalent to one occurrence roughly every 5,000 years for any given turbine.

In 2007, Garrad Hassan (now DNV GL) published a report discussing blade failure where it was confirmed that the 2005 Dutch Handbook projection of declining failure rates was accurate. It was further observed that the failure rate noted in the Dutch Handbook was "*particularly conservative in the context of current-day commercial wind turbines as the various root-causes of blade failure had been continuously addressed through developments in best practice in design, testing, manufacture and operation.*" [5]

Improvements in technology have resulted in both a decreased incidence of blade failure and in the severity of failure when it does occur. The Garrad Hassan Report observed that "*Even in the rare event of blade failure in modern machines, it is much more likely that the damaged structure will remain attached to the turbine than to separate.*" One reason for this is that in the event of structural failure, modern wind turbine blades are designed to buckle prior to any detachment, as a safety measure.

As per the 2014 Dutch Handbook, the typical throw distance for blade pieces or tips lies within one rotor diameter length, which would consist of up to 136 m from the wind turbine for the Desert Claim Project. The maximum reported throw distance for pieces of blade or tips was noted as being up to a distance of 500 m in the 2005 Dutch Handbook (one reported occurrence). DNV GL is not aware of reported blade debris beyond 500 m, but theoretical modelling shows that small fragments could be thrown slightly further under extreme conditions [1]. However, with the low estimated blade failure rates, the probability of a blade piece striking a human at close distance is very low and becomes extremely remote at further distances.

Under the UK HSE publication [2], a case study was performed for a modern 2.3 MW wind turbine. The risk of strike to an omnipresent person at a distance equivalent to 2 times the hub height (2H) was determined to be approximately 1 in 100,000,000 years. As stated in the study, this is roughly equivalent to the societal risk of an individual taking 2 commercial airplane flights per year. A common societal risk benchmark is the probability of being hit by lightning strike. With a rate of approximately 1 in 600,000 people hit by lightning in the USA per year, the risk to an omnipresent person at a 2H distance from a wind turbine would be 167 times less than being hit by lightning strike. For the Desert Claim project, this distance would be equivalent to 160-170 m from the wind turbines.

3 ICE SHEDDING

There are two phenomena associated with icing on a wind turbine structure. “Ice drop” refers to ice dropping from a structure in the immediate vicinity of the structure when the wind turbine is idle. This phenomenon can happen under specific meteorological conditions to any outdoor structure. “Ice throw” refers to ice fragments being projected at a distance by the rotating blades of the wind turbine when icing on the blades occurs and the blades are moving with enough speed to create this effect.

Winter operating protocols for modern turbines seek to reduce the risk of ice fragments hitting a person or structure by automatically or manually stopping the wind turbine when dangerous conditions exist. By definition, this type of operational protocol results in the reduction of ice throw hazard. As a result, a substantial amount of ice is shed locally as it thaws and slips off the blades with most of the ice dropping occurring in the immediate vicinity of the turbine, rather than being thrown.

From DNV GL’ experience, probability of ice drop decreases sharply beyond the wind turbine blade overhang distance. Under extreme wind conditions, it could extend to distances beyond 100m for modern large scale wind turbines, but does not exceed one rotor diameter from the wind turbine centre. The expected ice drop range for Desert Claim would be up to approximately 68m from the wind turbine, with some rare occurrences beyond 100m.

Early studies on ice throw suggested a simple empirical formula to determine the potential risk area without further site specific modelling, as explained under Seifert et al. [6]. The empirical formula is widely considered to be conservative. The area was defined as follows:

Maximum throw distance = (hub height + rotor diameter) X 1.5

For the Desert Claim Project, this would be equivalent to a maximum distance of 280 m to 330 m, which, in DNV GL’s experience, is in line with maximum theoretical throw distances, but beyond reported values. As stated under [6] and as proposed under the Garrad Hassan report [5], detailed risk modeling through advanced simulations is recommended in order to properly account for site-specific parameters and the probability of human presence or sensitive infratstructure. The area with non-negligible risk is typically a fraction of the empirical worst case area.

Similarly to tower collapse and blade failure, DNV GL notes that with over approximately 80,000 wind turbines worldwide operating in climates prone to icing, there have been no reported injuries to the public from ice drop or ice throw.

4 DESERT CLAIM SETBACKS REVIEW

DNV GL performed a review of the preliminary turbine layout configuration. The Project is located in a sparsely populated area, with low-intensity farming activity. The area is serviced by secondary roads with low vehicular traffic.

Project turbines will be sited at least 762 m (2,500 feet) from inhabited residences. This equates to a setback slightly greater than 5 times the tip height, using the dimensions for the largest proposed wind turbine technology. From DNV GL’s experience, this setback is superior to jurisdictions which apply setbacks for utility scale wind turbines. At this distance, the residences are beyond turbine failure or ice throw reach from the Project wind turbines.

Furthermore, the Project will implement additional setbacks consisting of 1.25 x turbine tip height from the nearby roads and 1 x turbine tip height from farm buildings, cattle round-up areas, etc. (i.e. other buildings/temporarily occupied farming areas). For the Project's largest turbines, this equates to setbacks of 188 m (615 feet) from roads and 150 m (492 feet) from other buildings. From DNV GL's experience, these setbacks are in line with best practices, and with ordinances tailored to wind energy.

A review of the preliminary layout indicates that 2 wind turbines (IDs B-13 and B-16) will be sited on either side of Reecer Creek Road, at approximately 220 m from the road. At this distance, and due to the low traffic expected on Reecer Creek Road, the risk from turbine failure and ice throw is expected to be extremely low. Turbine B-16 is also located approximately 200 m northwest from a farm equipment storage area, including a seasonal and temporary cattle storage area for transportation; at this distance, and due to the temporary occupancy nature of the area, the risk from turbine failure and ice throw is extremely low. All other wind turbines are sited further away from roads, farm buildings or temporarily occupied farming areas.

5 CONCLUSION

DNV GL has provided a preliminary evaluation of the risks for tower collapse, blade failure and ice throw for onshore wind farms based on technical literature and DNV GL's experience, and provided an opinion about the adequacy of the proposed Project setbacks. Based on the review, the risk of harm from tower collapse of blade failure is extremely remote, unless for stationary infrastructure within tip height of a wind turbine. The risk from ice is mostly limited to the area below the blade overhang, and slightly beyond, for ice drop. Ice throw can be reduced by implementing a carefully designed winter operation safety protocol.

From DNV GL's experience, a review of the Project's preliminary layout indicates that the setbacks are in line, or in excess, of typical setbacks for wind energy. Wind turbines are sited at distances where the risk can be expected to be extremely low, or even negligible for inhabited residences, due to the low traffic and temporary occupancy of nearby farm working areas.

Finally, with over 300,000 wind turbines operating worldwide, DNV GL is not aware of any injuries to the public from a wind turbine tower collapse or blade debris, and with over approximately 80,000 wind turbines worldwide operating in climates prone to icing, there have been no reported injuries to the public from ice drop or ice throw.

6 REFERENCES

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