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Analysis and Commentary:

Hazard Zones Resulting From Certain Defined Failures Of REpower MM92 Wind Turbines at the Desert Claim Project

Prepared For

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Background

KPFF has been requested by enXco to provide analysis and commentary on possible hazards resulting from certain failures of the specified REpower MM92 wind turbine assembly. The primary author of this report has completed a similar analysis of a similar turbine assembly for Kittitas County, Washington, in preparation of the Environmental impact Statement (EIS) for the Desert Claim Wind Power Project. This report draws from the literature search and calculations previously completed for those reports.

Three types of failures were identified for consideration in this report:

1. Blade Throw: Loss of an entire blade by failure at the hub attachment.
2. Tower Failure: Complete failure of the tower, particularly at the base.
3. Ice Throw: Ice accretions being thrown from a moving rotor.

It is prudent to consider the potential hazard zones created by various failure modes and take appropriate measures to mitigate risks. One of the most commonly employed means of managing these risks is the imposition of setbacks. It must therefore be noted that the calculations herein of potentially affected areas are idealized and simplified. Extensive modeling of risks associated with various failures has not been accomplished by the industry, and, because the risks are rare, it is not possible to corroborate the calculations with experiential data. The use of safety factors over and above calculated distances is recommended practice when determining setbacks.

Basics

The following data regarding wind turbine structural, machinery, operating and siting characteristics were provided by enXco and from the REpower MM 92 technical specification for this study.

Given:

- REpower MM92 wind turbine
- Location – Kittitas County, WA
- Rotor diameter – 92.5 meters (303 feet)
- Tower height – 80 meters (262.5 feet)
- Cutout wind speed – 24 m/s (54 miles per hour)
- Rotation speed – Maximum of 17 rpm (revolutions per minute)
- Tower base at same elevation as surrounding area.

It must be noted that (1) blade throw distances are mainly in the plain of rotation, not down wind and (2) the prevailing wind direction does not uniquely define wind direction at time of failure. Therefore **the potential hazard zone created by any failure should be considered as a circle with the tower at the center**. In other words, it is not safe or good practice to determine setbacks based on prevailing wind direction, unless the turbines are physically limited to that orientation.

Blade Throw

If a blade detaches from the rotor, its trajectory will be dependent upon the loading and stress state at the time of failure, and on the type and progression of failure before separation. This having been said, it is still useful to perform a simplified calculation of possible throw distance for use as a reference when considering setbacks. The simplified worst-case loss of a whole blade would occur with the blade rotating at maximum speed, when the blade is oriented at 45° from the vertical and rising. This is the classic maximum trajectory case from standard physics texts and yields the results in the table below as illustrated in **Figure A**. Review of these data indicates that for the REpower MM92 defined above, the maximum calculated blade throw distance is 152.3 m (500 ft.) from the tower to tip of the fallen blade.

The simplifications in this calculation can be summarized as follows. First, lacking detailed design data for the rotor blade, the blade center of gravity has been conservatively located as if the blade were of uniform thickness. In reality the blade CG is much closer to the hub so the actual initial kinetic energy would be much lower than estimated – perhaps by as much as 40%-50% - and the thrown distance will be proportionately reduced. Secondly, it is assumed that the blade travels and lands oriented parallel to its flight path (i.e., like a javelin) in plane with its original plane of rotation. Thirdly, drag forces along and perpendicular to the flight path are assumed to be extremely small compared to the weight (several tons) of each blade.

Blade Throw Distances

Turbine Model	Rotor Diameter	Rotor Speed	Tower Height	Blade Throw
REpower MM92	92.5 m (303 ft.)	17 RPM (max.)	80 m (262.5 ft.)	500 ft.

As mentioned previously, setbacks should be larger than the calculated maximum distance to account for the simplifications and uncertainties inherent in the calculations. KPFF conservatively recommends using a multiplier of 1.25, to establish a safety setback of 625 ft.

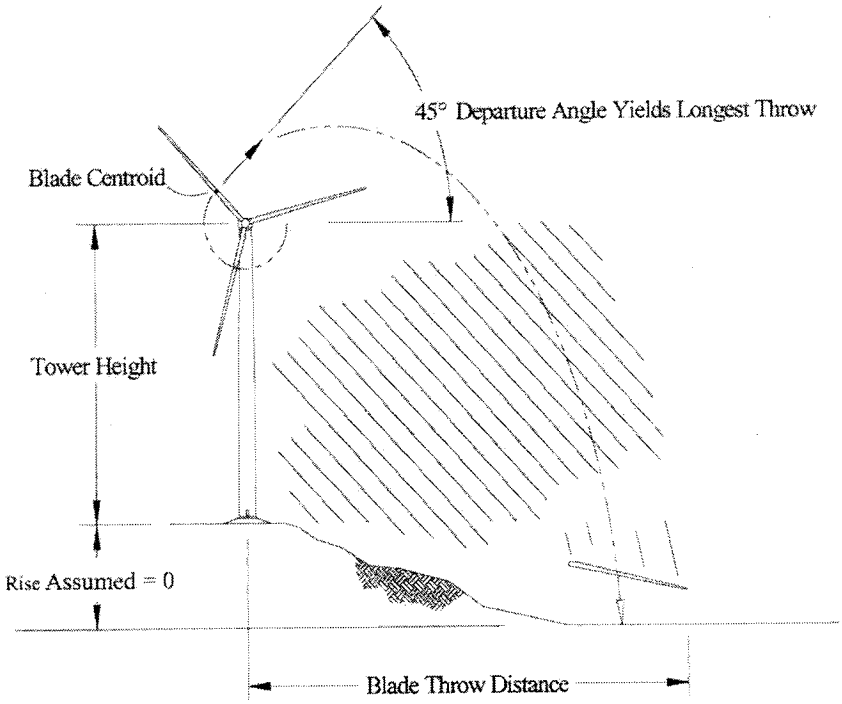

Figure A
Blade Throw Hazard Zone

Tower Collapse

Collapse of a turbine tower that has been constructed in accordance with international standards and local building codes is an extremely remote possibility. The Washington State Energy Facility Site Evaluation Council (2003) documented a personal communication with an insurance industry executive whose company insures over 12,000 wind turbines worldwide, indicating that he was not aware of any case of a tubular wind tower collapsing. In the unlikely event of a tower collapse, persons, animals and facilities within the area could be at risk of being struck by the tower, the nacelle or the turbine rotor blades. Each of these items weighs many tons, so it is reasonable to expect that being struck would result in damage, injury or death.

Failure of the tower at its base, or of its anchorage to the foundation, would create a hemispherical hazard zone with a radius approximately equal to the tower height (to the rotor centerline) plus one half of the rotor diameter. Persons, animals, and facilities within this radius would be at risk of being struck by the tower, generator assembly or rotor blades. For the specified REpower MM92 turbine and tower, the radius of the hazard zone under this scenario would be 126.3 meters (414 feet); this relates to a circular area at ground level of about 12.4 acres. Note that the area of potential impact due to tower collapse is smaller than that calculated for blade throw above.

Theoretically, it is also possible for tubular steel towers to buckle at some point along their length. Under this scenario the potential area of impact would be smaller than that of a tower failing at its base.

Ice Throw

Under certain conditions ice can form on wind turbine towers and rotor blades in a variety of ways. It has been observed that moving rotor blades are subject to heavier buildups of ice than stationary structures through the mechanism of rime icing (Morgan et al., 1998). Rime icing occurs when a sub-freezing structure is exposed to moisture-laden air with significant velocity. If the ice then becomes detached while the blades are rotating, there is the possibility of "ice throw" over a considerable distance from the turbine. Persons, animals and facilities within the ice throw hazard zone could theoretically be at risk of being struck by falling ice fragments.

Ice throw over 100 m (328 ft) has not been documented as a hazard and an ice throw injury report has not been found in the course of this or previous studies. One manufacturer recommends an ice throw exclusion zone with a radius of 125 m (410 ft) on the downwind side of the tower, which they cite as 125% of the largest recorded throw distance.

Summary of Findings

KPFF has conducted calculations that indicate a safety setback of 625 feet from each turbine tower will provide protection of people and facilities from the possibility of blade throw, tower failure and ice throw. Beyond this safety setback, no impacts from these hazards are expected.