HERMANVILLE-CLEARSPRING WIND DEVELOPMENT

Turbine Inspection and Condition Evaluation

Prince Edward Island Energy Corporation

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Task and objective:
This report presents the results of inspections conducted by DNV on behalf of Prince Edward Island Energy Corporation.

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Table of contents

Appendices

List of abbreviations

Abbreviation	Meaning
LE	Leading edge
LEE	Leading edge erosion
LPS	Lightning protection system
PS	Pressure side
RCA	Root cause analysis
SS	Suction side
SW	Shear web
TE	Trailing edge
UT	Ultrasonic testing

1 INTRODUCTION

Prince Edward Island Energy Corporation ("PEIEC" or the "Customer") retained DNV Canada Ltd., formerly DNV Energy Systems Canada Inc. ("DNV") to evaluate the turbine condition at the Hermanville-Clearspring wind project (the "Project"), located in Prince Edward Island, Canada. An overview of the Project is provided in Table 1-1.

This technical report provides findings from the condition assessment, including severity assessment where appropriate, information on associated risks, and recommended actions.

Table 1-1 Overview of the Hermanville-Clearspring wind project

Characteristic	Description
Location	Kings County, Prince Edward Island
Number of turbines	10
Turbine type	Acciona AW116/3000
Blade type	AW56.7
Total capacity [MW]	30.0
Commercial operation date	January 2014

Except in Table 1-1 above, Acciona or Nordex-Acciona are referred to as Nordex throughout this report, considering the legacy Acciona and legacy Nordex companies merged in 2016 and the consolidated company is now named Nordex.

2 SCOPE OF WORK

DNV reviewed available historic inspections footage as well as other technical information provided by the Customer (see Section 2.2) and inspected six out of ten Project turbines including internal and external blade inspections.

2.1 Site inspection

DNV representatives Malcolm Moore and Marina Curak of DNV's Wind Turbine Technology group visited the Project from 25 April 2022 to 29 April 2022 to assess the general operational condition of the turbines and blades. DNV met with PEIEC Operations Engineer Blair Arsenault prior to the inspections to develop an inspection plan. Turbines and blades were selected based on known issues and as such the number of findings of a specific failure mode may not be expected to be representative for the entire Project.

DNV conducted a comprehensive inspection of turbine T03 and all three of its blades, during which DNV noted all findings that may be expected to have an impact on the blade design life, if not addressed (severity category three or greater, as further defined in Section 2.3). The area between the trailing edge and the trailing edge shear web were not inspected at turbine T03. Following discussions with PEIEC, the scope of the remaining blade inspections was reduced to focus on more severe findings. In the reduced scope, DNV recorded findings that are, in DNV's opinion, likely to reduce the operational life of the blades if not addressed (categories four and five only). DNV also added inspection of the area of the blade between the trailing edge and the trailing edge shear web.

DNV performed internal and external inspections on seven blades. DNV also briefly inspected previously damaged and removed blades at turbines T03 and T10 as reference blades; however, as these blades had already been removed, these blades are not further considered in this report.

DNV inspected a total of six Project turbines, including visible portions of the foundation, the entrance decks, switchgear, the nacelle, hub interior, and anemometry equipment on the top of the nacelle. The turbine inspection did not include stopping between the entrance and yaw decks of the towers. Visual inspections were performed with a focus on major issues that could be significant at the conclusion of the original equipment manufacturer (OEM) warranty service term. The inspection methodology was developed from a list of typical inspection items the OEM performs during annual and semi-annual inspections. The severity categorization of turbine findings is presented in Section 2.4.

Findings of the blade and turbine inspections are listed in Table 3-1 and Table 3-2 respectively.

2.2 Historic records

DNV reviewed available information about the condition of the Project's turbines and blades, including the following documents:

- Nordex action plan of ongoing issues, dated April 2022 [3] and [4];
- Drone inspection records for all Project turbines, dated September 2021 [5]; and
- Internal blade inspection reports of the lightning protection system for turbines T01 through T06, dated August 2017 [6].

2.3 Blade finding severity categorization

Damage and defects are the leading causes of blades not reaching their intended design strength objectives (e.g., lifetime and/or resistance to extreme loads). Categorization of damage and defects in wind turbine blades is a challenging task that lacks guidance in the form of an industry standard. Standardization of an approach to categorization of damage and defects increases the efficiency and effectiveness of blade maintenance strategies. In an effort to move toward a standard damage and defect categorization system, Electric Power Research Institute (EPRI) has surveyed approximately 350 individuals across the spectrum of owners/operators of wind turbines, blade manufacturers, turbine manufacturers, blade repair service providers, consultants, and academics, to capture current practices in blade damage and defect categorization. Findings of the survey can be obtained from EPRI in its white paper 3002019669 titled "A White Paper on Blade Defect and Damage Categorization: Current State of the Industry," issued in December 2020 [1].

DNV utilized the EPRI categorization scale, numbered one though five, in the assessment of the findings at the Project. The severity categories are further described in Table 2-1 below.

Table 2-1 Categorization system for wind turbine blade damage and defects

Category	Characteristics	
1	**Description**	Minor variances from supply specifications but within acceptable (or industry typical) tolerances; may affect the appearance of the blade or blade feature. Though minor, can be useful to identify as position references, or for blade identification.
	Potential for growth	None expected.
	Impact to aerodynamics	None expected.
	Impact to life	None expected.
2	**Description**	Minor damage or defects that exceed supply specification acceptance criteria. Multiple cosmetic findings and/or a single major cosmetic finding that are damage, defects, or former repairs. Findings exceed tolerances of supply conditions or industry typical manufacturing variability. Repairs of more severe damage or defects can be recategorized to category 2 upon review of repair.

Category	Characteristics	
	Potential for growth	Not likely but may accelerate leading edge erosion when located on the leading edge, additionally may leave laminate or bond lines exposed to environmental degradation. Generally, 100% growth in size or severity pushes finding into next category.
	Impact to aerodynamics	May have minor impact to aerodynamics depending on details, though beyond what could reasonably be measured.
	Impact to life	None expected.
3	**Description**	Moderate to minor structural damage or minor manufacturing defects in non-critical areas. Features are moderately out of compliance with supply conditions and/or below minimum typical industry practice. May present as surface indications when in fact there is damage to the underlying structural laminate. Internal inspection may be needed to determine the extent of the finding. May be particularly challenging to assess criticality due to lack of design data such as load margins. Findings may be category 3 when category 4 actions seem too drastic and category 2 is not appropriate, because there is a slight risk of loss of structural capability.
	Potential for growth	Likely to increase in size or extent over time and become more severe. Growth in size or severity by 50% or more is likely to push finding into next category.
	Impact to aerodynamics	May have an impact to aerodynamics depending on details.
	Impact to life	Life is expected to be reduced without some other measures such as monitoring or repair or engineering evaluation (in the case where there is sufficient margin).
4	**Description**	Significant damage or defects that have notable impact to structural capability and/or aerodynamic performance.
	Potential for growth	Likely to increase in size or extent over time and become more severe. Growth in size or severity of 10-50% is likely to push finding into next category.
	Impact to aerodynamics	Likely to have an impact to aerodynamics depending on details.
	Impact to life	High confidence the blade will not achieve intended life.
5	**Description**	Severe degree of damage or defect such that there is a high risk of imminent failure.
	Potential for growth	Likely to rapidly increase in size or extent.
	Impact to aerodynamics	Likely to have an impact to aerodynamics depending on details.
	Impact to life	The blade is expected to fail within a short period of time if the turbine is operated.

2.4 Turbine finding severity categorization

Visual inspections were performed to evaluate the condition of turbine components accessible without disassembly. The approach was similar to periodic six-month or annual scheduled service inspection without performing service items such as filter changes, greasing, etc. An inspection checklist was used for each inspection and inspected items were categorized using a four-level scale, shown below in Table 2-2.

Table 2-2 Categorization system for wind turbine visual inspection damage classification

Category	Characteristics	
1	**Normal condition**	The component or equipment is typical for its age. May show some signs of wear although it is serviceable and no further action is needed.
2	**Early signs of wear or damage.**	Slightly damaged or worn equipment and/or missing part which presents no potential impact on turbine operation or safety. Despite no urgent corrective action is required, the damaged equipment or component should be repaired or replaced. Meanwhile the equipment or component should be monitored for progression of damage.

Category	Characteristics	
3	**Advanced signs of wear or damage.**	Equipment and/or missing part which presents a potential impact to the operation of the turbine and/or safety. Should be scheduled for repair or replacement in short term and no later than next scheduled service. Should be monitored until repairs or replacement takes place.
4	**Failed or missing components.**	The component has failed and/or missing and represents a critical impact to the operation of the turbine and/or a safety hazard. Component and wind turbine if deemed necessary must be taken out of service to prevent further damage. Immediate action to repair or replace is required before returning the component back to service.

The delineation between categories (e.g., 2 or 3) is somewhat dependent on DNV's interpretation of the data. Not all visual/photographic evidence is conclusive. The intent of the categorization is to present a general observation of the severity of the condition of the component and provide a concise summary to aid decisions regarding future maintenance. Additional inspections or investigation may result in a recategorization of these observations. Any damage or abnormal conditions were noted in the inspection checklists and photos were taken to document the condition.

3 FINDINGS

This section summarizes the findings from the site inspections, for both the blade inspections and the turbine inspections.

3.1 Blade findings

This section presents DNV's blade findings, with focus on findings with severity category four or five. The blade inspection findings are summarized in Table 3-1, with detailed inspection reports attached in Appendix A. Known issues and findings with severity categories four or five are further discussed in the subsequent sections, where each finding is described in general, followed by the Project status and DNV's recommendations. Additional information regarding known failure modes can be obtained from DNV's turbine technology review report in Appendix C.

Table 3-1 DNV blade inspection findings summary

<table>
<tr><th>Turbine ID</th><th>Blade ID</th><th>Trailing edge cracking</th><th>LPS damage</th><th>Blade stud failure</th><th>Shear web delamination</th><th>Shear web separation</th><th>Other notes/findings</th></tr>
<tr><td>T01</td><td>107</td><td>-</td><td>x</td><td>-</td><td>x</td><td>x</td><td>Debond of bulk head brackets, gap in core material</td></tr>
<tr><td rowspan="3">T03</td><td>090</td><td rowspan="3">Not verified during internal inspection, but damage was noted from the ground</td><td>x</td><td>-</td><td>x</td><td>x</td><td>Debond of bulk head brackets, air bubbles, white laminate</td></tr>
<tr><td>101</td><td>x</td><td>-</td><td>x</td><td>x</td><td>Air bubbles</td></tr>
<tr><td>109</td><td>x</td><td>-</td><td>-</td><td>-</td><td>Debond of bulk head brackets, air bubbles</td></tr>
<tr><td>T08</td><td>108</td><td>x</td><td>x</td><td>-</td><td>x</td><td>-</td><td>Air in laminate</td></tr>
<tr><td rowspan="2">T09</td><td>083</td><td>-</td><td>x</td><td>x</td><td>-</td><td>x</td><td>Three blade studs missing, missing leading edge shear clip, wrinkle</td></tr>
<tr><td>085</td><td>-</td><td>x</td><td>-</td><td>-</td><td>-</td><td>Evidence of lightning strike</td></tr>
</table>

3.1.1 Trailing edge cracking

Issue: Nordex informed DNV that trailing edge cracking in the AW56.7 blade model first occurred in March 2015. Multiple additional instances were observed later, including severe cracks that extended from the trailing edge to the spar cap. Such trailing edge cracks have been reported to occur at approximately 12 m from the blade root. Nordex had further reported that blades produced before 28 May 2013 were more susceptible to a manufacturing deviation and, as such, at a higher risk of cracking. Blades manufactured after that date have additional fiberglass layers in the critical area. The precise cause of the cracking has not yet been clearly demonstrated to DNV.

Trailing edge cracking can be detected by external visual inspections, such as during scheduled maintenance.

Project status: From previous drone inspection footage conducted by a third party in September 2021, nine instances of category five trailing edge cracking were observed at turbines T03, T08, T09, and T10. Additionally, the drone inspection reports note a number of less severe cases across the Project turbines. DNV reviewed the category five findings and agrees with the severity assessment. During DNV's internal blade inspections, trailing edge cracking was observed on turbine T08 (blade 108). The internal inspection of turbine T08 confirmed the high severity (category five) as observed from the drone inspection footage. During visual inspections from the ground, DNV confirmed trailing edge cracking affecting one blade of turbine T03.

DNV also observed a previous external blade repair at one blade on turbine T09, at approximately 12 m from the blade root. The blade repair was observed not to have a gel coat finish/topcoat, which would be included in an industry typical blade repair. In addition, from the drone inspections, trailing edge cracks (category five) were present on both sides (toward the tip and toward the blade root) of the repair.

Based on Nordex's repair schedule, blades 108 and 109 of turbine T08 were scheduled for repair in Q2 2022 and blade 083 of turbine T09 during Q3 2022 **Error! Reference source not found.**. During DNV's site visit, trailing edge repairs were ongoing at turbine T10.

Recommendations: Trailing edge cracking is a known issue for this turbine model and DNV considers it prudent practice to monitor all AW56.7 blades for development and progression of trailing edge cracks. PEIEC reported that internal and external blade inspections are to be performed on an annual basis [3]; however, based on the severity of some of the Project's trailing edge cracks, DNV recommends increasing the inspection frequency to at least semi-annual (every six months), which may be adjusted in subsequent years depending on the damage progression. Additionally, DNV recommends the Project perform drone-based external blade inspection of all Project blades in the near future to evaluate damage progression since the September 2021 inspections. Further, DNV recommends that category three and four findings are included in the Nordex's repair strategy planning.

Trailing edge cracks are repairable up-tower (without needing a crane) and Nordex has developed two repair instructions (IMTOC0231 and IMTOC0241) detailing the procedure for addressing cracks that have occurred. According to these procedures, these repairs can be completed either internally, as a provisional repair, or externally, as a permanent repair. DNV recommends at least provisional repairs be performed as soon as possible after identification of damage, especially for severe cases, such as category five trailing edge cracks. DNV did not observe evidence of provisional repairs on the inspected blades. DNV acknowledges the ongoing repair work and recommends the known cases of trailing edge cracking (category five) at the Project be addressed immediately and affected turbines be removed from operations until the damage is repaired. DNV recommends industry typical repair practices (including blade surface finishing) be adhered to.

In DNV's opinion there is high risk that blades with severe trailing edge cracking will not meet their 20-year design life. Provided that blade repairs are conducted in accordance with industry typical practices this risk would be reduced. Given the observed cases of trailing edge cracking in close proximity to previous repairs, DNV recommends continuous monitoring following repairs at least annually.

3.1.2 Lightning protection system damage

Issue: Following initial challenges with the lightning protection system (LPS) of the protype AW56.7 blades due to excessively tight cable routing, Nordex launched a root cause analysis (RCA) for LPS failures. Nordex identified four LPS failure modes:

1. Cable lug which connects the main LPS cable at the root to the cross-nut was broken.
2. Main conductor at R3.5 displaced from its original position, insulation damage, and in some cases, the cable was broken completely.
3. Main cable or terminal cable found broken (disconnected) at R15 or R30 near Tyco connector.
4. Main cable insulation damaged at R0, R3.5, R15 and/or R30, at the end of the over-lamination.

Out of all the blade manufacturers of this blade model (Acciona Blades, Aeris, TPI, and Indutch), TPI and Indutch were found to be unaffected by LPS failure modes. This is due to the braided cable used in TPI and Indutch blades, which is more flexible and ductile than the non-braided cable used in Acciona and Aeris blades. Nordex identified the low axial deformation capability of the cable in Acciona Blades and Aeris blades to be a contributing factor in each failure mode, which would explain why TPI and Indutch blades appear to be unaffected by these issues. Further, inadequate cable routing was identified as one of the root causes for the second failure mode and as a contributing factor for the third and fourth.

In DNV's opinion it is a reasonable conclusion that a combination of blade deformation, cable stiffness, and cable routing (e.g., through shear web holes) could produce sufficient strain levels to fail the cable. Failed cables may introduce the risk of internal arcing, which increases the risk of fire.

Project status: The Project's blades have the initial prototype design, where the LPS cable is connected on the trailing edge. All inspected blades had broken or damaged LPS connections at the root. DNV also observed two instances of lightning damage at turbine T09 (blade 083), where charring was present, and at turbine T09 (blade 085), where charring of the blade root area was observed (Figure 3-3). During the brief inspection of the blade on the ground at turbine T03, DNV observed lightning damage on the exterior of the blade on the pressure shell.

LPS inspections were conducted in 2017. DNV compared our 2022 findings to the LPS inspection reports from 2017. Previously-identified damage had not been addressed and continues to impact the functionality of the LPS (see Figure 3-1 and Figure 3-2). PEIEC confirmed that LPS repairs were not conducted following the 2017 LPS inspections [7].

Figure 3-1 Turbine T01 (blade 107) 2020 LPS damage at 0.5 m distance from the root

Figure 3-2 Turbine T01 (blade 107) 2017 LPS damage
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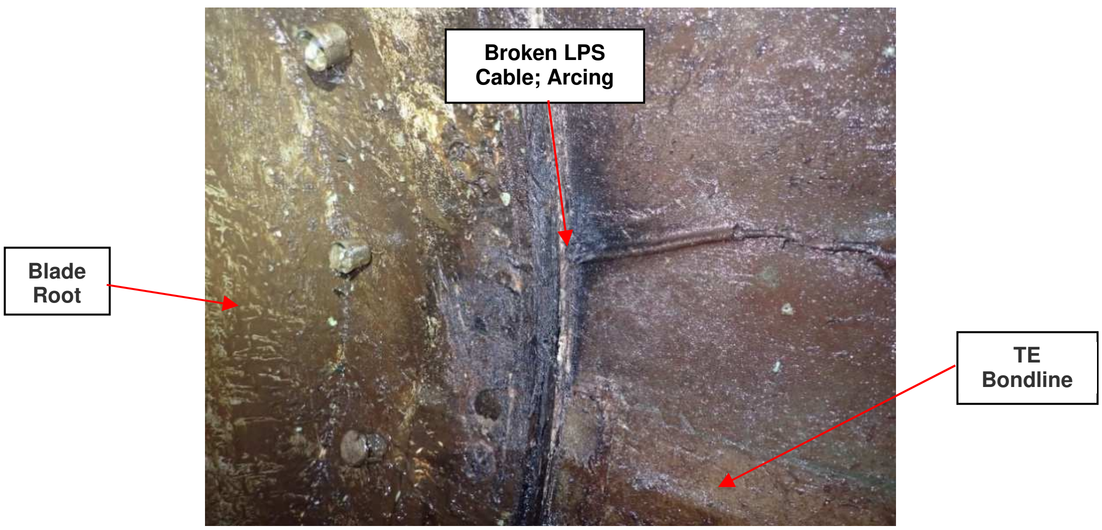


Figure 3-3 Broken LPS and evidence of arcing at turbine T09 (blade 085)

Recommendations: Nordex has developed two corrective actions for known LPS issues, which may be applied depending on the presence or lack of failures. Where LPS system failure(s) are present, IMTOC292 is applicable, which outlines a specific repair procedure for each failure mode. Further, as a proactive mitigation measure, Nordex also developed IRT1462 for blades in which a failure has not occurred. IRT1462 includes inspecting the cable lug at Z0, and repairing insulation damage, if applicable. Subsequently the main cable is released (disconnected) from the intermediate Tyco connectors at Z15 and Z30.

In the 2017 LPS inspection reports **Error! Reference source not found.**, several LPS failures and signs of charring were noted. DNV further observed evidence of charring during the internal blade inspections close to five years later, indicating continued malfunction of the LPS. Arcing within a blade presents the risk of structural damage to the blade and also may result in a fire. DNV recommends regular internal visual blade inspections, including inspecting the LPS. DNV further recommends that known LPS damage, which may significantly and adversely impact the LPS functionality, be repaired in a timely manner.

While DNV has not conducted a site-specific lighting risk assessment, based on the observed evidence of lightning impacts and the LPS damage observed in each inspected blade, in DNV's opinion there is high risk that future lightning damage beyond industry typical frequency and severity will occur unless LPS repairs are conducted.

During the site visit debrief on 29 April 2022, the PEIEC discussed with DNV that all blade LPS damage is covered by Nordex; however, the coverage does not include any non-blade damage (such as tower impact).In DNV's opinion, this additional coverage somewhat reduces commercial risk associated to blade lighting damage.

3.1.3 Broken blade studs and blade root cracking

Issue: DNV is aware that broken blade studs have been observed on some AW56.7 blades in the AW3000 fleet. According to Nordex, broken blade studs first occurred in March 2016, and an RCA was subsequently initiated. The RCA found two distinct failure modes: Type 1, where the stud failed at the T-bolt thread, and Type 2, where the stud failed in material away from the thread due to side loading.

For Type 1 failures, DNV understands that only blades manufactured in Nordex's Lumbier facility ("Lumbier blades") have been affected. For Type 2 failures, Nordex reported that the failures are caused by angular misalignment of the blade during the erection process, leading to increased side loading of the studs. Nordex developed an alignment pin to prevent movement during initial blade installation. DNV finds the root cause determination to be plausible.

Nordex has observed that Type 1 failures mainly occur in two circumferential locations around the blade root; these locations correspond to the highest fatigue loading on the studs. Nordex has concluded that the flatness of the root face of the blade is inducing bending in the studs, resulting in stud failure. With the information known to date, DNV concurs with Nordex's conclusion.

In addition to stud failures, Nordex has found that blades with Type 1 stud failures are experiencing circumferential cracking along the blade root face. Nordex has concluded that the circumferential cracking is also due to a lack of flatness of the blade root face.

When a blade stud failure occurs, it is possible that a portion of the blade stud will fall into the hub and cause damage (e.g., to a hydraulic line), which would generally cause a turbine fault. Consequently, it is expected that in addition to the replacement of the stud itself, some repairs and/or hydraulic oil cleaning will be required in the hub. Although this has not happened to date, in a worst-case scenario, should multiple blade studs fail nearly simultaneously, stud failures may progress and separation of the blade from the turbine could occur.

As of December 2020, Nordex has identified four corrective actions to address blade stud failures. These actions are applied sequentially. First, the tension of the stud will be increased, the second is to use a new stud design, next, a collared nut would be used, and finally the surface of the blade would be refaced. Nordex's aim of increasing blade bolt tension is to improve the contact between the blade and blade bearing. DNV understands the new stud design will have a coarser thread with improved behaviour with respect to fatigue. The collar nut c replaces standard nuts and washers with flanged nuts to reduce the number of interfaces and corresponding losses in preload due to embedment effects within the bolted joint for a given preload. Should these corrective actions prove insufficient to mitigate bolt breakage, Nordex recommends refacing the blade root, which requires bringing the blade down tower.

Project status: PEIEC informed DNV that the blade stud failures experienced at the Project originate in insufficient blade root flatness (Type 1 failure mode) and that the Project has experienced over 200 blade stud failures as of June 2022 [7].

Nordex has been tracking broken blade studs at the Project. At the time of the DNV site visit, two blades at turbine T02 and one blade each at turbines T05 and T09 had broken studs. DNV confirmed three blade studs were damaged at turbine T09. Also, DNV has observed minor paint chipping and signs of impact to the hub casting on multiple inspected turbines; the damaged appeared to DNV to be the result of a loose bolt or bolts within the hub during operation.

Based on Nordex action tracker [3], this issue has been ongoing at the Project at least since July 2018 and Nordex appears to have been providing regular RCA updates to PEIEC, most recently in March 2022. Replacement studs appeared to be the same as original studs and DNV did not observe collar nuts. Further DNV is not aware of refacing activities having taken place at the Project. DNV did not verify the blade bolt tension.

While the Nordex action tracker and the blade repair plan note a blade root crack at turbine T03 (blade 101), DNV did not observe blade root cracking during our inspection of this blade, although it should be noted that it is extremely difficult to actually observe the root cracking visually when a blade is mounted on the hub. Furthermore, nearly all blade internal surfaces were covered with significant amounts of oil and water; as such the blade root crack may not have been detectable during DNV's inspection. UT or other inspection methods are typically recommended to properly identify blade root cracking while blades are mounted on the hub.

Recommendations: In DNV's opinion, Nordex suggested corrective actions, other than refacing the blade root, do not address the root cause, which Nordex has indicated is a lack of root face flatness. Further, from DNV's perspective, an "industry typical" number of broken blade studs is near-zero, and when blade stud failures are identified, they should be replaced rapidly, otherwise the loads are transferred to adjacent bolts which can then in turn fail. A cascading effect of many broken bolts could lead to a catastrophic failure of the blade.

In DNV's opinion, tension increase may delay stud failures, or reduce stud failure rates by reducing fatigue loading on studs. However, increasing the tension in the studs does not address the root cause, and as such is not likely to completely eliminate stud failures.

DNV expects this issue may result in future downtime for stud replacement and cause consequential damage in the hub. Even if minimal or no blade root cracking has yet been observed at the Project, DNV is of the opinion that blade root cracking may develop in the future. DNV recommends blade root refacing on an at-risk basis (e.g., refacing blades with the most broken bolts first) to mitigate risks of reduced blade life due to root cracking. Following Nordex's alternative corrective actions (increased tension of the stud, install new stud design and/or install a collared nut) may reduce stud failure rates; however, in DNV's opinion, the only robust mitigant is blade root refacing. Until blade root refacing is done, DNV recommends that inspections using ultrasonic testing (UT) or other methods be done on a regular basis to determine whether blade root cracking is occurring.

3.1.4 Shear web separation

Issue: DNV is aware that AW56.7 blades have experienced separation (also referred to as debonding) between the shear web and shell. Such shear web separations have been reported to occur along the bondline between the main shear web flange and shell, mostly observed on the suction side of the shear web. Partial to full separation has been observed from R3.5 to beyond R20.

Nordex's hypothesis is that a defect in the web-to-shell bond is present, and the defect is of sufficient severity that normal loading leads to crack initiation and progression to web separation. The root causes identified by Nordex are all related to the manufacturing process, not the blade design itself. Nordex provided updates to DNV throughout the RCA process and DNV considers Nordex's identified root cause to be generally plausible.

As of November 2020, Nordex has advised that while multiple blades have been affected by web separation, no catastrophic blade failures have occurred due to web separation. For the existing fleet, Nordex recommends repairing the adhesion and installing shear clips to support the main shear web up to 20 m into the blade.

Project status: DNV has observed 11 instances of shear web adhesive cavities/voids, which were categorized at severity levels three or lower.

DNV observed reinforcement using shear clips as recommended by Nordex in all inspected blades except at turbine T09 (blade 83), where shear clips were not installed between from R7.4 to R13.3.

PEIEC did not report any recent repair had been carried out for shear web separations [7].

Recommendations: The addition of shear clips up to 20 m inside the blade is a prudent risk mitigation against shear web separation. In DNV's opinion, the shear clips reduce the risk of blade failures due to shear web separation to industry-typical levels. DNV recommends installation of shear clips be confirmed for all Project blades (e.g. during scheduled maintenance intervention) and the shear clips be installed at any Project turbines where they have not been installed up to 20 m inside the blade.

Additionally, DNV recommends the Project's blades be inspected for shear web separation and that known cases are either repaired or monitored regularly (at least annually, and possibly more frequently depending on the severity of the separation) for damage progression.

3.1.5 Wrinkle

Issue: Wrinkles are manufacturing defects that result from errors during the layup and/or infusion process. Wrinkles can cause stress concentrations and cracks may initiate at wrinkles depending on the severity and location of the wrinkle.

Project status: DNV observed one wrinkle with severity category four at turbine T09 (blade 083), which showed signs of crack initiation.

Recommendations: While damage may not progress from the wrinkle at turbine T09 (blade 083), DNV recommends monitoring this wrinkle on at least an annual basis for damage progression. If no damage progression is identified, the monitoring frequency may be adjusted.

3.1.6 Shear web delamination

Issue: DNV is aware of a known issue affecting the AW56.7 blade model, where delamination occurs on the trailing edge side of the main shear web, at the corner between the face sheet and flange of the shear web. The spanwise location of the delamination varies; however, the delamination occurs in nearly all cases on the pressure-side flange of the shear web. Nordex's hypothesis is that air bubbles (voids) and a resin-rich area in the corner where delamination appears to initiate are resulting in stress concentrations, and sufficient energy is available to allow the delamination to initiate and progress. Nordex's analyses reasonably show that delamination may initiate and propagate under normal loading in the presence of flaws such as voids in the corner of the web flange. In DNV's experience, resin-rich areas in shear web flange corners, and voids in these resin-rich areas, are common in blades, yet delamination at this location due to these features is uncommon. Nonetheless, in DNV's opinion, Nordex's hypothesis explaining delamination is generally reasonable, and Nordex's has identified the contributing factors that are likely leading to the delamination.

As of June 2020, Nordex has advised that while multiple blades have been affected by delamination, no catastrophic blade failures have occurred due to delamination. Further, Nordex has conducted over 13,000 risk-based blade inspections (also inspecting for shear web separation) to better understand the damage mode and track damage propagation, if any. Despite the presence of delamination in the AW56.7 blade models, which is not industry-typical, successful completion of a full-scale blade test (using a blade that had delaminated) and operating history to date suggest that blades with delamination are capable of meeting their 20-year design life. Therefore, DNV generally considers the AW56.7 with delamination present to have industry-typical risk associated with meeting their 20-year design life. Nordex also intends to continue inspecting a limited blade population in the AW3000 fleet exhibiting delamination to monitor for any remaining potential issues, although in DNV's opinion Nordex's inspection protocol (inspecting from the hub rather than via blade entry) will only detect significantly progressed blade damage. Should any findings become relevant to the fleet, Nordex may revise the inspection criteria for AW56.7 blades exhibiting delamination.

Project status: The Nordex action plan [3] includes an item described as "Blade Delamination," which had been closed in January 2019 after the final RCA report had been delivered to PEIEC. DNV has not independently reviewed this RCA report, which is understood to be specific to the Project.

While on site, DNV observed 12 instances of shear web delamination with severity category three. Some instances of shear web delamination had previously been marked and damage propagation since that time was observed. As such, the shear web delamination at turbine T03 (blade 90) was observed to have progressed by 4.68 m to a total length of 18.36 m since the prior inspection in 2018.

Recommendations: DNV recommends continuous monitoring for shear web delamination, as recommended by Nordex. If no growth in damage over time is observed, an engineering assessment may result in downgrading the finding severity to category two.

3.2 Turbine findings

This section outlines and describes the turbine issues observed on site, Project status, and DNV's recommendations. As discussed in Section 2.1, DNV inspected most parts of the turbine, including visible portions of the foundation, the entrance decks, switchgear, the nacelle, hub interior (unless otherwise indicated), and anemometry equipment on the top of the nacelle. The turbine inspection did not include stopping between the entrance and yaw decks of the towers. The turbine inspection reports are summarized in Table 3-2 and detailed inspection reports are listed in Appendix B.

Table 3-2 DNV turbine inspection findings summary

Turbine ID	DNV turbine inspection	Excessive oil / water	Loose or missing hardware	Corrosion present	Other notes/findings [1]
T01	Yes	-	x	-	One yaw motor is missing a fan. There is excessive brake dust, which is indicative of yaw brake drag, the elastomer bearings have moderate wear, and the placement bolts have sheared from the elastomer pad. The pitch slipring wiring cover is removed.
T02	No	-	-	-	As of 30 May 2022, reported not operational due to main bearing failure [8].
T03	Yes	x	x	-	The pitch slip ring missing protection cover, and oil is pooling inside the junction box. One blade is missing both hatches (bulk head and the blade root area), which is a significant safety risk. There was significant amount of grease in hub.
T04	No	-	-	-	As of 30 May 2022, reported not operational due to main bearing failure [8].

[1] Only turbine findings of categories three or four are noted (see Section 0 for severity definitions)

Turbine ID	DNV turbine inspection	Excessive oil / water	Loose or missing hardware	Corrosion present	Other notes/findings [1]
T05	No	-	-	-	As of 30 May 2022, reported not operational due to main bearing failure [8].
T06	Yes [2]	x	x	x	The yaw motors are missing their cover (rotor windings were exposed). The main bearing had failed. The flexible coupler was not installed. The vibration switch plug on PCH sensor is secured with zip ties and electrical tape.
T07	Yes [2]	x	x	-	Severe grease leakage on nacelle structure/housing. The vibration switch plug on PCH sensor is secured with zip ties and electrical tape.
T08	Yes	x	x	x	Standing water in basement floor. The main control cabinet service key switch not connected. Main power cable splices' spacer was damaged. Severe oil leak in the nacelle belly. One generator levelling-nut was loose.
T09	Yes	x	x	x	Yaw motor parts observed laying on nacelle platform
T10	No	-	-	-	As of 30 May 2022, reported not operational due to main bearing failure [8].

3.2.1 Blade bearing

Issue: AW116 turbines are known to be affected by blade bearing cracking, which eventually leads to blade bearing failures. The AW116 blade bearings are supplied by Laulagun and Rothe Erde, though the issue largely impacts Laulagun-supplied bearings. Nordex has implemented several containment measures for operational projects that have bearings manufactured before April 2015 (such as the Project's bearings), which include the use of reinforcement plates (IRT1017). Nordex previously confirmed to DNV that the IRT1017 retrofit has been completed throughout the AW116 fleet.

The radial cracks have reportedly occurred through the outer ring at the centerline of the upper row ball filling bore. Other bearings failed due to development of a radial crack adjacent to the ball fill hole. The cause of the failures was seen as the result of a superimposition of several macro and micro notch effects, which results in a high stress concentration. Specifically, the ball filling bores in conjunction with the bores for the pin hole and/or the mounting bolt bores are the macro notches, while the surface roughness within these bores is viewed as micro notches. The reported conclusion of the failure was that cracks were developed due to the high surface roughness in the pin hole securing the plug in the ball filling bore and/or in the mounting bolt bores. Several other contributing factors were identified during Nordex's RCA. As a result of these investigations, corrective actions were implemented and are referred to as the first re-design (implemented by June 2015) and the second re-design (implemented by February 2016).

Nordex has reported that no issues or failures have been reported for AW116 turbines which had the bearings manufactured after June 2015. The changes to the bearing design, certification, and improvements to the surface roughness of the mounting bolt bores are positive steps in resolving the blade bearing issue.

Project status: DNV is aware that blade bearings have cracked on the site, and most of the blade bearings have been replaced. As of 7 April 2022 [3], six "old style," presumably original, blade bearings have been reported to be in operation at the Project, which are inspected every six months. The last inspection was scheduled for March 2022 and it is DNV's understanding that following such inspections replacements are scheduled as needed. DNV was not able to identify the

[2] Hubs were not inspected due to high winds

design state of the replacement bearings but based on the start of commercial operations of the Project, DNV considers it likely that most replacement bearings have the second re-design. That said, early blade bearing failures, within the first two years of operation may have received inferior blade bearings.

Recommendations: DNV generally recommends for turbines with the old blade bearing design, all on-site retrofits IRT1017, IRT1110, and IRT1191 to be installed. DNV is of the opinion that while the proposed retrofits may reduce the risk of blade bearings failing over the 20-year life, some risk remains, especially if the bearings have been in operation for significant periods prior to the retrofits and crack initiation may have already taken place. DNV considers the risk for blade liberation to be moderate to high if defective blade bearings are not addressed in a timely manner.

DNV considers the risk of original blade bearings not meeting the 20-year design life is moderate to high, even if all retrofits have been implemented. First re-design blade bearings are expected to have a low risk of not meeting the 20-year design life and DNV considers the level of risk associated with the second re-designed blade bearing to be industry typical, given the accumulated track record.

DNV recommends confirming the number of original bearings in operation and further identifying the number of installed bearings with the “first re-design” (manufactured before February 2016), if any. Further, DNV recommends that blade bearing replacements be accounted for in the O&M budget, in accordance with the installed blade bearing design revisions.

3.2.2 Main bearing

Issue: While DNV was at the Project, turbine T6 was offline due to a main bearing failure. DNV has not been provided with further information about the failure mode or the status of the investigation. Main bearing failures are not known to systematically affect AW116 turbines. While on site, the technicians informed DNV that a misalignment of the main bearing and main shaft had been observed at turbine T6, which DNV did not independently verify.

Project status: Subsequent to DNV’s site visit, PEIEC informed DNV on 30 May 2022 [8] that an additional four turbines, T02, T04, T05, and T10 had been stopped due to main bearing failures. Additionally, PEIEC noted that Nordex confirmed that only a few main bearing failures were observed in Brazil, and that it was not a common failure mode for the AW116 turbine model. PEIEC informed DNV on 13 June 2022, that an RCA has been initiated and initial borescope inspections revealed damage on both the front and the rear main bearings [7].

Recommendations: DNV does not have adequate information to assess the risk of the main bearing failures at the Project. However, DNV considers the current main bearing failure rate at the Project to be above industry typical expectations, and DNV recommends an RCA for the main bearing failures be conducted by Nordex.

3.2.3 Yaw brake noise

Issue: The AW116 turbine is equipped with six electric yaw motors and eight or ten hydraulic yaw brakes. PEIEC reported audible yaw brake noises have occurred at the Project in the past; the yaw noise has reportedly been traced down to grease and oil contamination of the yaw ring [8].

According to the site’s action tracker [3], vibrations due to worn brake callipers has also been known to affect the Project. DNV is not aware of a systematic yaw noise or yaw calliper issues affecting AW116 turbines.

Project status: Nordex tracked turbines experiencing an audible yaw noise and at the time of the site visit 60% of Project turbines were reported to be affected (turbines T01, T03, T04, T05, T06, and T09). DNV did not observe excessive yaw noise during the site visit and consequentially, DNV was not able to confirm the issue and its root cause.

As of 7 April 2022, the site’s action tracker identified new callipers have been ordered, which had been an open item since at least July 2018 [3].

Recommendations: Yaw callipers are generally expected to meet the 20-year design life and given the relatively early failure of these at the Project, DNV would recommend further investigation of the root cause to mitigate future failures. DNV also recommends considering proactive procurement of spare yaw callipers for the remaining turbines at the Project. DNV considers there to be a small risk that yaw vibrations may increase the wear of yaw system sub-components.

DNV expects an industry typical time to address yaw brake noise would be within a few scheduled maintenance schedules (maximum of two years).

3.2.4 Yaw motor and brake issues

Issue: During DNV's site visit, the site's O&M turbine issue's tracking board listed multiple yaw motors and yaw brakes bypassed, with two failed yaw drives. DNV is not aware of the root cause of these issues, but it is DNV's understanding that defective motors and brakes where bypassed to enable turbine operation, with reduced number of motors/brakes active. DNV is not aware of a systematic yaw drive or yaw brake issues affecting the AW116 turbine model and DNV has not been informed about any specific issues with these systems at the Project.

Project status: DNV observed failed and or bypassed yaw motors at a total of four turbines (T01, T06, T08, and T09). Replacement of a yaw motor at turbine T08 was ongoing during DNV's site visit. DNV observed one yaw brake at turbine T02 to be bypassed.

Recommendations: Yaw components are subject to wear and as such a certain level of failures are expected at any project, especially as the components age. DNV considers bypassing defect yaw motors to be an adequate temporary solution (a few days or weeks) to minimize downtime while preparing for a service intervention. That said, during this period the yaw capability, especially during high wind events and/or highly turbulent winds, may be compromised, although DNV expects minimal impact on production would be noted. Given the high number of faults present during DNV's site visit, DNV recommends inquiring with Nordex, whether any systematic issues have been investigated and or identified and if so, whether mitigation measures can be implemented to reduced unscheduled service interventions. DNV also recommends more spare parts be ordered for these components, if this is one of the reasons why these failures have not been addressed rapidly, as DNV would normally expect yaw motor and brake issues to be addressed rapidly (within a few days) rather than being bypassed and allowing turbines to run with bypassed motors for extended periods.

3.2.5 Pitch cylinder failures

Issue: The AW116 pitch cylinder are attached to the hub casting via trunnion bearings, which in turn sit in bushings. These bushings are known to wear out over time and if not replaced, trunnion bearing failures occur. Consequential to the failure of the bearings, the pitch ram may become loose, cause damage to the hub interior and compromise the pitch system functionality.

Project status: Trunnion bearing failures are tracked by the Project. Poor trunnion bearing conditions were noted for turbines T08 and T09 and the trunnion bearings at turbine T05 required inspection. Failures of the trunnion bearings have been tracked in Nordex's action tracker since July 2019 and replacements were scheduled to be completed on all Project turbines by September 2021. PEIEC reported Nordex annually inspects the trunnion bearings [7]. DNV is unaware of the downtime or lost energy that is associated to pitch cylinder failures at the Project.

Recommendations: DNV considers trunnion bearing failures to be common in the AW116 turbine model and considers it typical industry practice to inspect the bushings and bearings during scheduled maintenance. DNV recommends downtime /lost production associated to pitch cylinder failures be further investigated. If severe downtime is associated to pitch cylinder failures (related to trunnion bearing failures), DNV recommends replacing the trunnion bearings and bushings with a more robust design to reduce service interventions.

DNV considers tracking of the bushing and bearing conditions to be good practice and it is likely to decrease troubleshooting efforts in case of a failure. That said, compromised functionality of the pitch system, a critical sub-system in a turbine's safety chain, may in an extreme case have safety relevant impacts and consequentially maintaining high reliability of the pitch system is generally recommended. DNV would expect that known cases of deteriorating trunnion bearings or bushings be replaced within six months, thus preventing a failure that would halt the turbine until repair/replacement is done.

4 CONCLUSION AND RECOMMENDATIONS

In order to assess the current Project condition and the status of known issues affecting the Project turbine models and the mitigating measures taken, DNV inspected the site including internal and external blade inspections. To further inform DNV's opinion, historic inspection footage and technical information provided by PEIEC were reviewed. Table 4-1 summarizes the previously discussed issues, including the Project status, DNV's recommended actions and provides a high-level conclusion of each issue, comparing against industry expectations for turbines of this model and vintage.

DNV did not conduct an interview with site management following the document review and turbine inspections. Further, DNV did not receive RCA reports for review that have been issued to the Project in the past. Therefore, some Project specific details may not have been known to DNV and consequently may not have not been taken into consideration in this review.

Table 4-1 Conclusions and recommendations

Issue	Project status	DNV recommendation	DNV conclusion on issue resolution
Trailing edge cracking	Nine instances of category five trailing edge cracking were observed at the Project (drone inspections, September 2021). A number of less severe cases across the Project was noted. Three instances are scheduled for repair in 2022 and additionally DNV observed one repair ongoing during DNV's site visit.	• At least provisional repairs be performed as soon as possible after identification of damages. • Increasing the inspections frequency to at least semi-annual (every six months). • The Project should perform drone-based external blade inspection of all Project blades in the near future. • The known cases of trailing edge cracking (category five) at the Project be addressed immediately and affected turbines be removed from operations until the damage is repaired. • Industry typical repair practices (including blade surface finishing) be adhered to.	The status of trailing edge cracks and associated resolution is below industry expectations.
Lightning protection system damages	DNV noted LPS damage (severity category three and four) on all seven inspected blades and observed two instances of lightning damage. No resolution has been observed.	• Regular internal visual blade inspections, including inspecting the LPS and that known damage be repaired in a timely manner.	The status of LPS damages and the lack of associated resolutions is below industry expectations.
Broken blade studs and blade root cracking	At the time of the site visit four blades were operating with at least one broken blade stud.	• Blade root refacing on an at-risk basis (e.g., refacing blades with the most broken bolts first) to mitigate risks of reduced blade life due to root cracking.	The status of failing blade studs and the appeared lack of effective resolutions is

Issue	Project status	DNV recommendation	DNV conclusion on issue resolution
	No resolution has been observed.	• Broken blade studs, when identified, should be replaced rapidly to avoid further failures.. • Until blade root refacing is done, inspections using UT or other methods be done on a regular basis to determine whether blade root cracking is occurring.	below industry expectations.
Shear web separation	Eleven instances of shear web adhesive cavities/voids category three or lower were observed. DNV observed shear web bond reinforcement using shear clips.	• Installation of shear clips be confirmed for all Project blades (e.g. during scheduled maintenance intervention) and the shear clips be installed at any Project turbines where they have not been installed up to 20 m inside the blade. • The Project's blades be inspected for shear web separation at least yearly and that known cases are either repaired or monitored regularly.	The status of shear web separation and the observed resolution is mostly consistent with industry typical expectations for AW116 blades.
Wrinkles	DNV observed one wrinkle with damage severity category four.	• Monitoring this wrinkle at least annually for damage progression.	The status of wrinkles is consistent with industry typical expectations.
Shear web delamination	DNV observed 12 instances of shear web delamination with severity category three. DNV noted damage progression affecting at least one blade.	• Monitoring for shear web delamination, as recommended by Nordex.	The status of shear web delamination is consistent with industry typical expectations for AW116 blades.
Blade bearings	Twenty-four out of 30 blade bearings have been reported as replaced. The six original bearings are inspected every six months.	• For turbines with the old blade bearing design, all onsite retrofits IRT1017, IRT1110 and IRT1191 to be installed. • Identifying how many bearings of the "first re-design", if any, have been installed at the Project and that blade bearing replacements be accounted for in the O&M budget accordingly.	The status of blade bearing failures is consistent with industry typical expectations for AW116 turbines.
Main bearing	As of 30 May 2022, 50% of Projects turbines were stopped due to main bearing failures. A RCA is ongoing.	• A RCA for the main bearing failures be conducted by Nordex.	The number of main bearing failures is higher than industry typical expectations. Conducting a RCA is an industry typical measure at this time.
Yaw brake noise	At the time of the site visit 60% of Project turbines were reported to be affected by excessive yaw noise.	• Further investigation of the root cause to mitigate future failures. • Considering proactive procurement of spare yaw callipers for the remaining turbines at the Project.	The yaw brake noise appears not to be consistent with industry expectations.
Yaw issues	DNV observed failed and/or bypassed yaw motors at a total of four turbines and one bypassed yaw brake.	• Inquiring with Nordex, whether any systematic issues have been investigated and/or identified and if so, whether mitigation measures can be implemented to reduced unscheduled service interventions.	Some level of yaw system failures may be expected, although the number of bypassed yaw motors is not consistent with industry expectations.
Pitch cylinder failures	Poor trunnion bearing conditions were noted for two turbines and the trunnion bearings at	• Downtime/lost production associated to pitch cylinder failures be further investigated. If severe downtime is associated to pitch cylinder failures (related to trunnion bearing failures), replacing the	Some level of pitch cylinder failures is expected; further evaluation needed for

Issue	Project status	DNV recommendation	DNV conclusion on issue resolution
	turbine T05 required inspection.	trunnion bearings and bushings with a more robust design to reduce service interventions.	DNV to provide opinion compared to industry typical expectations.

5 REFERENCES

[1] EPRI, “A White Paper on Blade Defect and Damage Categorization: Current State of the Industry,” Palo Alto, CA:2020. 3002019669.

[2] Electric Power Research Institute (EPRI), “A White Paper on Blade Defect and Damage Categorization: Current State of the Industry,” Document number: 3002019669 dated 2020.

[3] Nordex, “Hermanvilel Action Tracker April 7 2022.cleaned.xlsm,” received 6 April 2022.

[4] Nordex, “PEI 2022 Repair plan.cleaned,” received 6 April 2022.

[5] Skyspecs, “Damage Summary Report”, dated 1 September 2021.

[6] Unknown author, “Internal LPS Inspections Checklist_Hermanville-Clear_Springs_WF, T01,” dated 21 August 2017.

[7] Email Blair Arsnault (PEI) to Adam Chehouri (DNV), “RE: DNV Energy Systems Canada Inc. - Canadian amalgamation Client communication,” dated 13 June 2022.

[8] Email Blair Arsnault (PEI) to Adam Chehouri (DNV), “RE: DNV Energy Systems Canada Inc. – Canadian amalgamation Client communication,” dated 30 May 2022.

APPENDIX A – BLADE INSPECTIONS

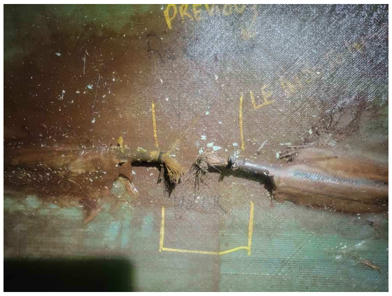
A.1 Turbine T01

A.1.1 Blade 107 Findings

A.1.1.1 Findings - 1

Finding ID	001
Inspection date	04-29-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	PS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	1.30
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	480.00
Finding Span-wise Length (mm)	200.00
Finding category	4
Photo	

A.1.1.2 Findings - 2

Finding ID	002
Inspection date	04-29-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	SS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	1.30
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	300.00
Finding Span-wise Length (mm)	250.00
Finding category	3
Photo	

A.1.1.3 Findings - 3

Finding ID	003
Inspection date	04-29-2022
Finding Type	Debond
Component	Adhesive
Position in Blade	N/A
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.00
Distance measured from Bulkhead(m)	0.00
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	0.00
Finding category	3
Photo	
Description/Comments	Bulkhead L brackets 2 of 6 not adhered

A.1.1.4 Findings - 4

Finding ID	004
Inspection date	04-29-2022
Finding Type	Delamination
Component	LE shear web
Position in Blade	LE SW PS TE Flange Radius
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	15.70
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding Span-wise Length (mm)	8200.00
Finding Chord-wise Width (mm)	0.00
Finding category	3
Photo	

A.1.1.5 Findings - 5

Finding ID	005
Inspection date	04-29-2022
Finding Type	Void
Component	LE shear web
Position in Blade	LE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	9.26
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1380.00
Finding Span-wise Length (mm)	3200.00
Finding category	3
Photo	

A.1.1.6 Findings - 6

Finding ID	006
Inspection date	04-29-2022
Finding Type	Gap
Component	Core material
Position in Blade	SS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	9.29
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	55.00
Finding Span-wise Length (mm)	8.00
Finding Chord-wise Width (mm)	40.00
Affected Area Percent (%)	100.00
Finding category	3
Photo	

A.2 Turbine T03

A.2.1 Blade 090 Findings

A.2.1.1 Findings - 1

Finding ID	001
Inspection date	04-26-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	TE
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	1.20
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	60.00
Finding Span-wise Length (mm)	200.00
Finding Chord-wise Width (mm)	10.00
Finding Depth (mm)	10.00
Finding Height (mm)	10.00
Affected Length (mm)	160.00
Finding category	4
Photo	

A.2.1.2 Findings - 2

Finding ID	002
Inspection date	04-26-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	TE
Location (Internal or external)	INT
Distance measured from Root Face(m)	
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	1.16
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	240.00
Finding Span-wise Length (mm)	106.00
Finding Chord-wise Width (mm)	10.00
Finding Depth (mm)	10.00
Finding Height (mm)	10.00
Affected Length (mm)	105.00
Affected Width (mm)	10.00
Finding category	4
Photo	

A.2.1.3 Findings - 3

Finding ID	003
Inspection date	04-26-2022
Finding Type	Debond
Component	Adhesive
Position in Blade	N/A
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	0.00
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	0.00
Finding category	2
Photo	
Description/Comments	Bulkhead L brackets (4 of 6) not adhered

A.2.1.4 Findings - 4

Finding ID	004
Inspection date	04-26-2022
Finding Type	White laminate
Component	Laminate
Position in Blade	LE Bonding Flange
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	3.96
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	80.00
Affected Length (mm)	1720.00
Affected Width (mm)	18.00
Affected Area Percent (%)	40.00
Finding category	3
Photo	
Description/Comments	Delamination at LE bondline flange

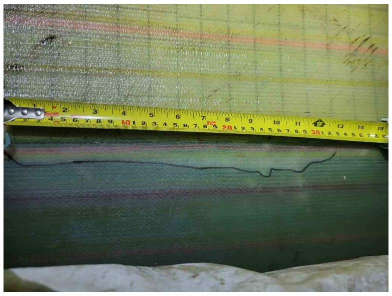
A.2.1.5 Findings - 5

Finding ID	005
Inspection date	04-26-2022
Finding Type	Delamination
Component	LE shear web
Position in Blade	LE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	3.32
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1150.00
Finding Span-wise Length (mm)	580.00
Finding Chord-wise Width (mm)	35.00
Affected Area Percent (%)	95.00
Finding category	3
Photo	

A.2.1.6 Findings - 6

Finding ID	006
Inspection date	04-26-2022
Finding Type	Void
Component	LE shear web
Position in Blade	LE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	11.40
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding Span-wise Length (mm)	7010.00
Finding category	3
Photo	
Description/Comments	Cavity from Z11.40 to 18.36; growth from 13.68. last inspection 09-2-18

A.2.1.7 Findings - 7

Finding ID	007
Inspection date	04-26-2022
Finding Type	Dry glass
Component	Spar cap
Position in Blade	LE SW LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	17.40
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	750.00
Finding Span-wise Length (mm)	345.00
Finding Chord-wise Width (mm)	35.00
Affected Area Percent (%)	100.00
Finding category	3
Photo	

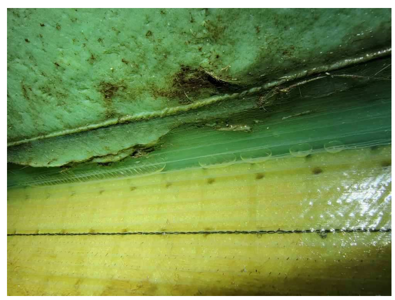
A.2.1.8 Findings - 8

Finding ID	008
Inspection date	04-26-2022
Finding Type	Delamination
Component	LE shear web
Position in Blade	LE SW Bondline PS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	5.83
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1300.00
Finding Span-wise Length (mm)	330.00
Finding Chord-wise Width (mm)	10.00
Affected Area Percent (%)	80.00
Finding category	3
Photo	

A.2.1.9 Findings - 9

Finding ID	009
Inspection date	04-26-2022
Finding Type	Delamination
Component	LE shear web
Position in Blade	LE SW Bondline PS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	10.56
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1340.00
Finding Span-wise Length (mm)	1800.00
Finding Chord-wise Width (mm)	25.00
Affected Length (mm)	1800.00
Affected Width (mm)	25.00
Affected Area Percent (%)	100.00
Finding category	3
Photo	
Description/Comments	Delamination at Z8.7 to Z10.5

A.2.1.10 Findings - 10

Finding ID	010
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	TE shear web
Position in Blade	TE SW Bondline PS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	13.00
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	1500.00
Finding Span-wise Length (mm)	105.00
Finding category	2
Photo	

A.2.2 Blade 101 Findings

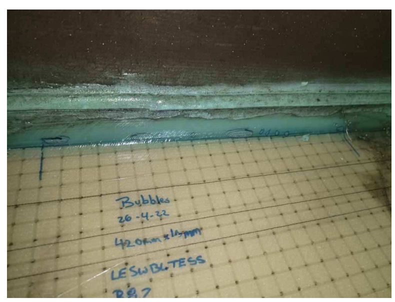
A.2.2.1 Findings - 1

Finding ID	001
Inspection date	04-26-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	PS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	1.40
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	300.00
Finding Span-wise Length (mm)	160.00
Finding Chord-wise Width (mm)	10.00
Finding Depth (mm)	10.00
Finding Height (mm)	10.00
Affected Length (mm)	160.00
Affected Area Percent (%)	100.00
Finding category	4
Photo	

A.2.2.2 Findings - 2

Finding ID	002
Inspection date	04-26-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	SS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	1.37
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	400.00
Finding Span-wise Length (mm)	130.00
Finding Chord-wise Width (mm)	10.00
Affected Area Percent (%)	100.00
Finding category	4
Photo	
Description/Comments	Insulation damaged/missing from LPS cable

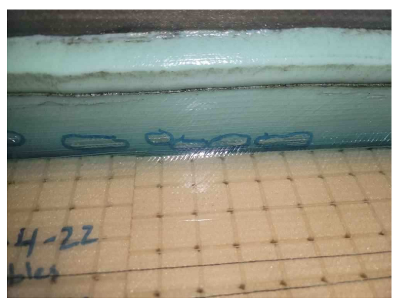
A.2.2.3 Findings - 3

Finding ID	002
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	LE shear web
Position in Blade	LE SW Bondline SS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	8.70
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding Span-wise Length (mm)	420.00
Finding Chord-wise Width (mm)	10.00
Affected Area Percent (%)	45.00
Finding category	3
Photo	

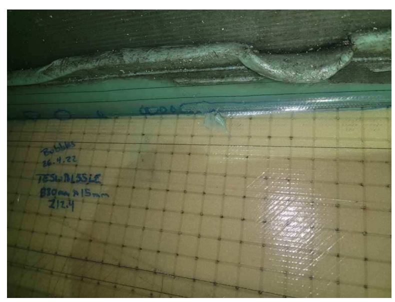
A.2.2.4 Findings - 4

Finding ID	004
Inspection date	04-26-2022
Finding Type	Delamination
Component	LE shear web
Position in Blade	LE SW Bondline PS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	8.80
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding Span-wise Length (mm)	2700.00
Finding Chord-wise Width (mm)	30.00
Affected Length (mm)	2700.00
Affected Width (mm)	30.00
Affected Area Percent (%)	100.00
Finding category	3
Photo	

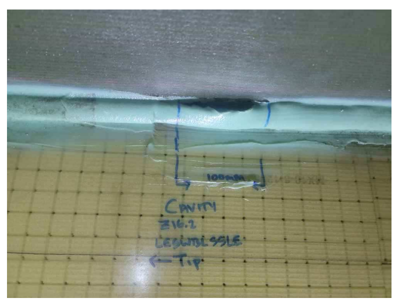
A.2.2.5 Findings - 5

Finding ID	005
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	LE shear web
Position in Blade	LE SW Bondline SS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	14.50
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding Span-wise Length (mm)	700.00
Finding Chord-wise Width (mm)	14.00
Affected Area Percent (%)	65.00
Finding category	3
Photo	

A.2.2.6 Findings - 6

Finding ID	006
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	TE shear web
Position in Blade	TE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	12.40
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1000.00
Finding Span-wise Length (mm)	830.00
Finding Chord-wise Width (mm)	10.00
Affected Area Percent (%)	65.00
Finding category	3
Photo	

A.2.2.7 Findings - 7

Finding ID	007
Inspection date	04-26-2022
Finding Type	Void
Component	LE shear web
Position in Blade	LE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	16.20
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1100.00
Finding Span-wise Length (mm)	100.00
Finding Chord-wise Width (mm)	3.00
Affected Length (mm)	100.00
Affected Width (mm)	3.00
Affected Area Percent (%)	100.00
Finding category	3
Photo	

A.2.3 Blade 109 Findings

A.2.3.1 Findings - 1

Finding ID	001
Inspection date	04-26-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	PS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	2.74
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	650.00
Finding category	4
Photo	

A.2.3.2 Findings - 2

Finding ID	002
Inspection date	04-26-2022
Finding Type	Debond
Component	Adhesive
Position in Blade	N/A
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	0.00
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	900.00
Finding category	3
Photo	
Description/Comments	Blade bulk head L brackets (2 of 6) not adhered

A.2.3.3 Findings - 3

Finding ID	003
Inspection date	04-26-2022
Finding Type	Wrinkle
Component	Shell
Position in Blade	SS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	2.66
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	25.00
Finding Span-wise Length (mm)	2030.00
Finding Chord-wise Width (mm)	1200.00
Affected Area Percent (%)	10.00
Finding category	2
Photo	
Description/Comments	18 chordwise wrinkles with 85mm to 140 mm spacing in between

A.2.3.4 Findings - 4

Finding ID	004
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	LE shear web
Position in Blade	LE SW Bondline PS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	7.87
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1340.00
Finding category	3
Photo	

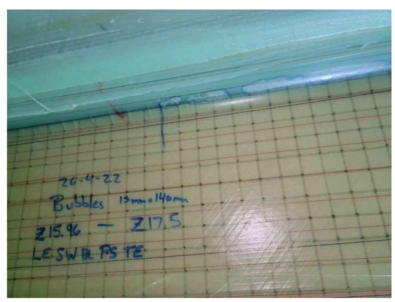
A.2.3.5 Findings - 5

Finding ID	005
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	LE shear web
Position in Blade	LE SW Bondline PS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	12.65
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding Span-wise Length (mm)	85.00
Finding Chord-wise Width (mm)	15.00
Affected Area Percent (%)	100.00
Finding category	3
Photo	

A.2.3.6 Findings - 6

Finding ID	006
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	LE shear web
Position in Blade	LE SW Bondline PS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	11.45
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding category	2
Photo	

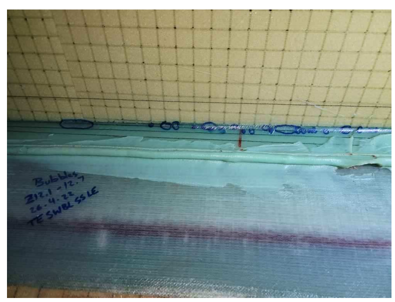
A.2.3.7 Findings - 7

Finding ID	007
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	LE shear web
Position in Blade	LE SW Bondline PS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	15.96
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding Span-wise Length (mm)	1500.00
Finding Chord-wise Width (mm)	15.00
Affected Area Percent (%)	60.00
Finding category	3
Photo	

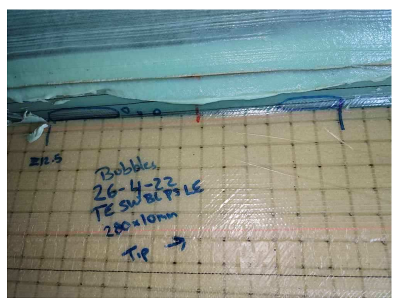
A.2.3.8 Findings - 8

Finding ID	008
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	LE shear web
Position in Blade	LE SW Bondline SS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	16.60
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding Span-wise Length (mm)	1850.00
Finding Chord-wise Width (mm)	15.00
Affected Area Percent (%)	45.00
Finding category	2
Photo	

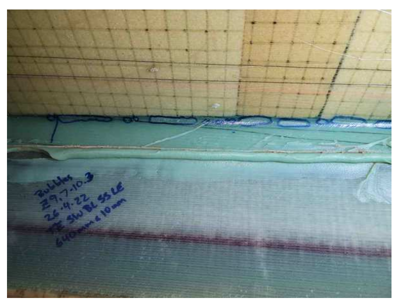
A.2.3.9 Findings - 9

Finding ID	009
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	TE shear web
Position in Blade	TE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	12.10
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	1000.00
Finding Span-wise Length (mm)	690.00
Finding Chord-wise Width (mm)	11.00
Affected Area Percent (%)	60.00
Finding category	3
Photo	

A.2.3.10 Findings - 10

Finding ID	010
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	TE shear web
Position in Blade	TE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	12.50
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1000.00
Finding Span-wise Length (mm)	280.00
Finding Chord-wise Width (mm)	10.00
Affected Area Percent (%)	60.00
Finding category	3
Photo	

A.2.3.11 Findings - 11

Finding ID	011
Inspection date	04-26-2022
Finding Type	Air/bubbles
Component	TE shear web
Position in Blade	TE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	9.40
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	1000.00
Finding Span-wise Length (mm)	640.00
Finding Chord-wise Width (mm)	10.00
Affected Area Percent (%)	90.00
Finding category	3
Photo	

A.3 Turbine T08

A.3.1 Blade 108 Findings

A.3.1.1 Findings - 1

Finding ID	001
Inspection date	04-28-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	PS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	1.50
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	300.00
Finding Span-wise Length (mm)	400.00
Finding Chord-wise Width (mm)	20.00
Affected Length (mm)	400.00
Affected Width (mm)	20.00
Affected Area Percent (%)	400.00
Finding category	4
Photo	

A.3.1.2 Findings - 2

Finding ID	002
Inspection date	04-28-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	SS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	1.50
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	400.00
Affected Length (mm)	250.00
Affected Width (mm)	25.00
Finding category	4
Photo	

A.3.1.3 Findings - 3

Finding ID	003
Inspection date	04-28-2022
Finding Type	Delamination
Component	LE shear web
Position in Blade	LE SW Bondline PS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	7.25
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1400.00
Finding Span-wise Length (mm)	12500.00
Finding Chord-wise Width (mm)	40.00
Affected Area Percent (%)	100.00
Finding category	3
Photo	

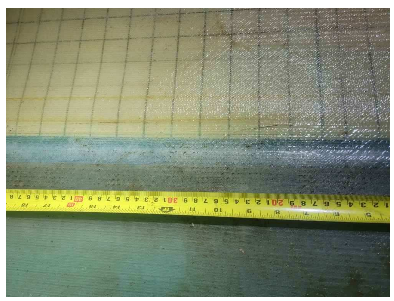
A.3.1.4 Findings - 4

Finding ID	004
Inspection date	04-28-2022
Finding Type	Delamination
Component	LE shear web
Position in Blade	LE SW Bondline PS TE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	24.00
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	800.00
Finding Span-wise Length (mm)	5600.00
Finding Chord-wise Width (mm)	35.00
Finding category	3
Photo	

A.3.1.5 Findings - 5

Finding ID	005
Inspection date	04-28-2022
Finding Type	Crack
Component	Shell
Position in Blade	TE
Location (Internal or external)	INT
Distance measured from Root Face(m)	
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	11.94
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	0.00
Finding Span-wise Length (mm)	3.00
Finding Chord-wise Width (mm)	50.00
Finding category	5
Photo	

A.3.1.6 Findings - 6

Finding ID	006
Inspection date	04-28-2022
Finding Type	Delamination
Component	Spar cap
Position in Blade	SS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	6.14
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	850.00
Finding Span-wise Length (mm)	9360.00
Finding Chord-wise Width (mm)	35.00
Affected Length (mm)	9360.00
Affected Area Percent (%)	95.00
Finding category	4
Photo	
Description/Comments	Z6.14 to Z15.1 LE spar cap, LE side.

A.4 Turbine T09

A.4.1 Blade 083 Findings

A.4.1.1 Findings - 1

Finding ID	001
Inspection date	04-27-2022
Finding Type	Blade stud
Component	Root T-bolt
Position in Blade	N/A
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.00
Distance measured from Bulkhead(m)	0.00
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	30.00
Finding category	3
Photo	
Description/Comments	3 T-bolts missing

A.4.1.2 Findings - 2

Finding ID	002
Inspection date	04-27-2022
Finding Type	Wrinkle
Component	Shell
Position in Blade	PS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	1.10
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1680.00
Finding category	4
Photo	

A.4.1.3 Findings - 3

Finding ID	003
Inspection date	04-27-2022
Finding Type	Void
Component	LE shear web
Position in Blade	LE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	12.54
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1300.00
Finding Span-wise Length (mm)	2300.00
Affected Length (mm)	700.00
Affected Area Percent (%)	31.00
Finding category	3
Photo	

A.4.1.4 Findings - 4

Finding ID	004
Inspection date	04-27-2022
Finding Type	Observation
Component	Over laminate
Position in Blade	LE SW Bondline SS LE Side
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	13.30
Distance from LE or TE	LE
Distance measured from LE or TE(mm)	1100.00
Finding Span-wise Length (mm)	10000.00
Finding Chord-wise Width (mm)	200.00
Affected Length (mm)	10000.00
Affected Width (mm)	500.00
Affected Area Percent (%)	100.00
Finding category	4
Photo	
Description/Comments	Missing position A shear clip from Z7.4 to Z13.3

A.4.1.5 Findings - 5

Finding ID	005
Inspection date	04-27-2022
Finding Type	Other
Component	LPS cable
Position in Blade	PS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	0.66
Distance measured from Bulkhead(m)	2.64
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	600.00
Finding Span-wise Length (mm)	180.00
Finding Chord-wise Width (mm)	40.00
Affected Length (mm)	180.00
Affected Width (mm)	40.00
Affected Area Percent (%)	100.00
Finding category	4
Photo	
Description/Comments	Lighting damage on overlaminate of LPS cable on PS. Exit charring present

A.4.2 Blade 085 Findings

A.4.2.1 Findings - 1

Finding ID	001
Inspection date	04-27-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	PS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	-0.26
Distance measured from Bulkhead(m)	3.40
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	550.00
Finding Span-wise Length (mm)	100.00
Finding Chord-wise Width (mm)	15.00
Affected Area Percent (%)	100.00
Finding category	3
Photo	

A.4.2.2 Findings - 2

Finding ID	002
Inspection date	04-27-2022
Finding Type	Broken
Component	LPS cable
Position in Blade	SS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	-0.26
Distance measured from Bulkhead(m)	3.40
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	370.00
Finding Span-wise Length (mm)	60.00
Finding Chord-wise Width (mm)	1.00
Affected Area Percent (%)	100.00
Finding category	4
Photo	

A.4.2.3 Findings - 3

Finding ID	003
Inspection date	04-27-2022
Finding Type	Observation
Component	Laminate
Position in Blade	PS
Location (Internal or external)	INT
Distance measured from Root Face to Bulkhead(m)	-0.26
Distance measured from Bulkhead(m)	0.55
Distance from LE or TE	TE
Distance measured from LE or TE(mm)	500.00
Finding Span-wise Length (mm)	150.00
Finding Chord-wise Width (mm)	150.00
Affected Area Percent (%)	95.00
Finding category	4
Photo	
Description/Comments	Evidence of lightning strike/arcing at LPS termination point. Charred laminate/glass multiple layers deep. Missing bulkhead in blade.

APPENDIX B – TURBINE INSPECTIONS

WIND TURBINE VISUAL INSPECTION	Wind Farm:	Hermanville Wind farm	DNV
	Wind Turbine:	T-1	

Inspection Data

Wind Turbine (WT):	T-1	*Inspector:*	Malcolm Moore
Wind Farm (WF):	Hermanville Wind farm	*Date:*	April 29, 2022
WF Location:	Souris, PEI, Canada	*From/To:*	8:50 AM 1:30 PM

Wind Turbine Data

WT Make:	Acciona	*Rated Power (kW):*	3,000
WT Model:	AW-3000/116	*Hub Height (m):*	92
Commissioned:	2014	*Rotor Diameter (m):*	116

Wind Turbine Components Identification

	Manufacturer	*Model/Type*	*Serial No.*
Gearbox:	*Winergy*	*PZAB 3535,0*	*NFC-4851057-0310-1*
Generator:	*Indar*	*TAR630XA6N60N*	*21516000007*
Blade A:	*Acciona*	*AW56.7*	*107*
Blade B:	*Acciona*	*AW56.7*	*102*
Blade C:	*Acciona*	*AW56.7*	*105*

Inspection Summary

Component Classification

	2	3	4	Total
1. Tower Foundation				
2. Turbine Controls	1			1
3. Service Lift/Climb Assist	1			1
4. Tower Sections				
5. Yaw System	1	1		2
6. Hydraulic System	1			1
7. Nacelle	1			1

	2	3	4	Total
8. Main Shaft				
9. Gearbox	1	2		3
10. Generator		1		1
11. Top Box Controller	1			1
12. Hub Assembly & Pitch	1			1
13. Blades		1		1
14. Safety System				
Total	8	5	0	13

Visual Inspection Damage Classification

1	**Normal condition**	The component or equipment is typical for its age. May show some signs of wear although it is serviceable and no further action is needed.
2	**Early signs of wear or damage.**	Slightly damaged or worn equipment and/or missing part which presents no potential impact on turbine operation or safety. Despite no urgent corrective action is required, the damaged equipment or component should be repaired or replaced. Meanwhile the equipment or component should be monitored for progression of damage.
3	**Advanced signs of wear or damage.**	Equipment and/or missing part which presents a potential impact to the operation of the turbine and/or safety. Should be scheduled for repair or replacement in short term and no later than next scheduled service. Should be monitored until repairs or replacement takes place.
4	**Failed or missing components.**	The component has failed and/or missing and represents a critical impact to the operation of the turbine and/or a safety hazard. Component and wind turbine if deemed necessary must be taken out of service to prevent further damage. Immediate action to repair or replace is required before returning the component back to service.

1. Tower Foundation

Item	System / Component	Comments	Photo	Class
1.01	Foundation concrete condition			1
1.02	Foundation bolts condition			1
1.03	Tower external wall condition			1
1.04	Tower verticality check			1
1.05	Padmount transformer condition			1
1.06	Tower stairs condition			1
1.07	Tower door condition			1

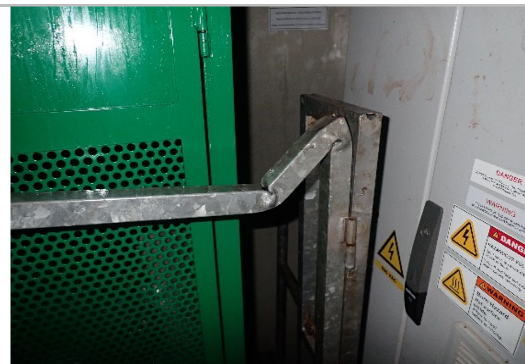
1.08	Tower door flange and seals			1
1.09	Tower door hinges and lock			1
1.10	Tower door screens and filters			1
1.11	Cleanliness of basement area			1

2. Turbine Controls

Item	System / Component	Comments	Photo	Class
2.01	Main control cabinet			1
2.02	Control panel			1
2.03	Cooling system			1
2.04	Converter			1
2.05	Breakers, switches, fuses			1
2.06	Cabling, splices			1
2.07	Grounding			1
2.08	Fans & filters			1
2.09	Light fixtures & LV	Tower light does not function		2
2.10	HV Switch gear cabinet	Switchgear cabinet missing hardware		1
2.11	HV Switch gear control cable			1
2.12	HV Switch gear gauge check			1

3. Service Lift/Climb Assist

Item	System / Component	Comments	Photo	Class
3.01	Overall condition			1

3.02	Lift entry cage	Lift gate damaged		2
3.03	Functionality of manual descent			1
3.04	Functionality of sensors			1

4. Tower Sections

Base Section

Item	System / Component	Comments	Photo	Class
4.01	Platform condition			1
4.02	Ladder condition			1
4.03	Safety cable condition			1
4.04	Hatch condition			1
4.05	Tower flange condition			1
4.06	Tower walls condition			1
4.07	Bolts condition, ping test			1
4.08	Grounding straps			1
4.09	Light fixtures and LV			1
4.10	Cabling, Splices			1

Mid Section(s)

Item	System / Component	Comments	Photo	Class
4.11	Platform condition			
4.12	Ladder condition			
4.13	Safety cable condition			
4.14	Hatch condition			
4.15	Tower flange condition			
4.16	Tower walls condition			
4.17	Bolts condition, ping test			
4.18	Grounding straps			
4.19	Light fixtures and LV			
4.20	Cabling, Splices			

Top Section

Item	System / Component	Comments	Photo	Class
4.21	Platform condition			
4.22	Ladder condition			
4.23	Safety cable condition			
4.24	Hatch condition			
4.25	Tower flange condition			

4.26	Tower walls condition			
4.27	Bolts condition, ping test			
4.28	Grounding straps			
4.29	Light fixtures and LV			
4.30	Cabling, Splices			

5. Yaw System

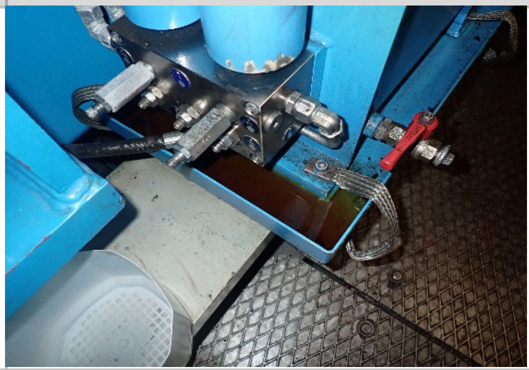
Yaw Deck

Item	System / Component	Comments	Photo	Class
5.01	Platform condition	Trash/debris reamains on yaw deck		2
5.02	Access ladder condition			1
5.03	Hatch condition			1
5.04	Safety cable top assembly			1
5.05	Grounding straps			1
5.06	Light fixtures and LV			1
5.07	Saddle cable condition			1
5.08	Torque check yaw ring			1
5.09	Yaw clamp condition			1
5.10	Yaw clamp manifold lines			1

Yaw Components

Item	System / Component	Comments	Photo	Class
5.11	Yaw motors condition	Yaw motor missing fann, excessive brake dust indicative of brake drag		3
5.12	Yaw motors oil level, leakage			1
5.13	Yaw gear condition			1
5.14	Yaw gear lubrication			1
5.15	Yaw counter condition			1
5.16	Yaw position sensor condition			1

6. Hydraulic System

Item	System / Component	Comments	Photo	Class
6.01	Hydraulic pump condition	Moderate leakage from hydraulic unit		2
6.02	Accumulator condition			1
6.03	Hoses and couplings			1
6.04	Oil level, pressure			1
6.05	Radiator condition			1

7. Nacelle

Item	System / Component	Comments	Photo	Class
7.01	Main frame structural condition			1
7.02	Fiberglass condition, seams			1
7.03	Insulation, soundproofing			1
7.04	Light fixtures and LV	LV outlet cover missing		2
7.05	MV Cabling, strain reliefs			1
7.06	Grounding straps			1
7.07	Nacelle hardware, condition			1
7.08	Hub adapter bolts, condition			1
7.09	Rotor lock condition			1
7.10	E-stop functionality			1
7.11	Hoist condition			1
7.12	Hatches, condition			1
7.13	Nacelle tie offs			1
7.14	Anemometer condition			1
7.15	Wind vane condition			1
7.16	Lightning receptor			1
7.17	Met mounting bracket			1

8. Main Shaft

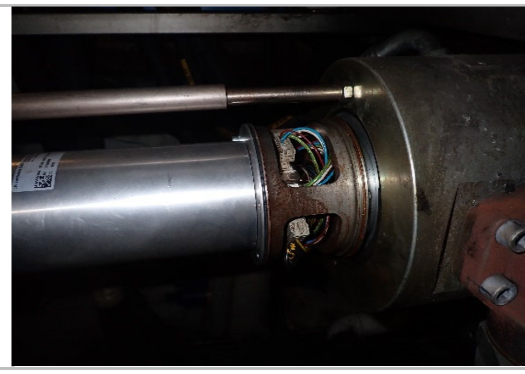
Item	System / Component	Comments	Photo	Class

WIND TURBINE VISUAL INSPECTION	Wind Farm:	Hermanville Wind farm
	Wind Turbine:	T-1

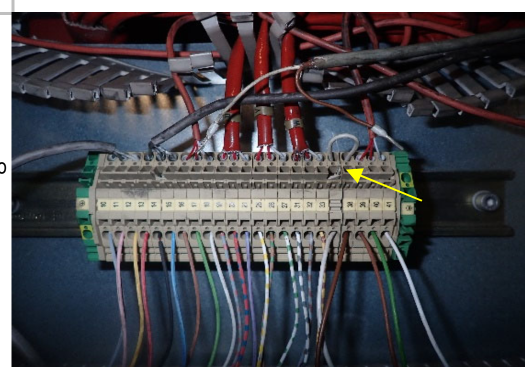
8.01	Main bearing condition			1
8.02	Main bearing mounting hardware			1
8.03	Main shaft condition			1
8.04	Shrink disc condition			1
8.05	Shrink disc mounting hardware			1
8.06	Grease trap			1
8.07	Rotor plate deformation			1
8.08	Rotor plate shield			1

9. Gearbox

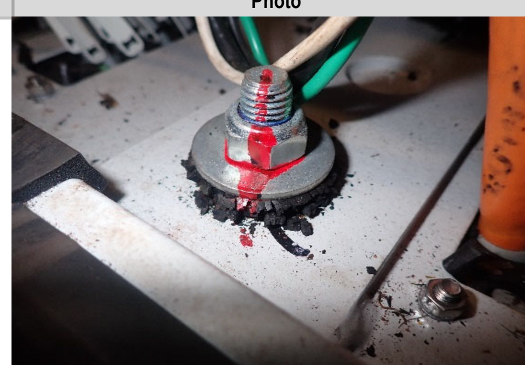
Item	System / Component	Comments	Photo	Class
9.01	Gearbox cover condition			1
9.02	Gearbox mounting hardware	Elastomer bearing with moderate wear, placement bolt sheared for elastomer pad		3
9.03	Gearbox access ports			1
9.04	Cooling system/circuit	Cooling line pressure gauge damaged / needle		2
9.05	Lubrication pump system			1
9.06	Breather filter condition			1
9.07	Gearbox oil level			1
9.08	Oil filtration system condition			1
9.09	Hoses and couplings			1

9.10	Pitch slip-ring, rotating union	Rotating union/slipring wiring cover removed		3

10. Generator

Item	System / Component	Comments	Photo	Class
10.01	Generator cover condition			1
10.02	Generator feet torque markings			1
10.03	Cooling system/circuit			1
10.04	Lubricant system			1
10.05	Generator bearings			1
10.06	Generator slip ring			1
10.07	MV cable condition, strain relief	Melting of raceway and signs of excessive heat to cables; bypassed temperature sensor pin 37 to pin 38		3
10.08	Brake disc condition			1
10.09	Brake clamps and calipers			1
10.10	Flexible coupler condition			1
10.11	Flexible coupler torque marks			1
10.12	Flexible coupler safety cover			1

11. Top Box Controller

Item	System / Component	Comments	Photo	Class
11.01	Control cabinet condition	Top box mount bushing degrading		2
11.02	Air extraction fan filters			1

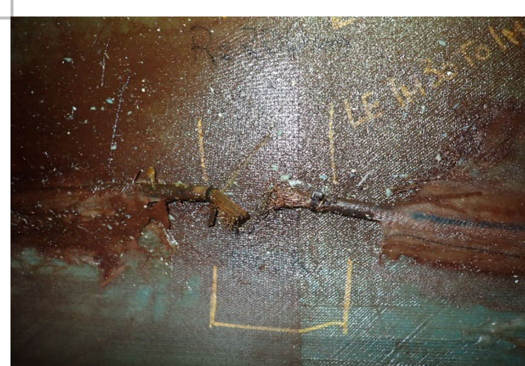
11.03	Wire Connections and Cabling			1
11.04	Grounding			1

12. Hub Assembly & Pitch

Item	System / Component	Comments	Photo	Class
12.01	Mounting hardware condition			1
12.02	Access hatch condition			1
12.03	Blade bearing seals			1
12.04	Fiberglass nose cone condition			1
12.05	Cleanliness hub internal			1
12.06	Blade internal protective covers			1
12.07	Rotating union condition			1
12.08	Control box condition			1
12.09	Light fixture and LV			1
12.10	Hydraulic system leaks			1
12.11	Pitch accumulator condition			1
12.12	Pitch ram cylinder condition	Pitch ram connection plate deflected/damaged		2
12.13	Pitch cylinder bearing condition			1
12.14	Pitch cylinder connection points			1

13. Blades

Blade 1

Item	System / Component	Comments	Photo	Class
13.01	Blade structural condition			1
13.02	Blade connection torque			1
13.03	Blade surface			1
13.04	Blade LPS	LPS cable damaged		3
13.05	Blade cleanliness			1

Blade 2

Item	System / Component	Comments	Photo	Class
13.06	Blade structural condition			1
13.07	Blade connection torque			1
13.08	Blade surface			1
13.09	Blade LPS			
13.10	Blade cleanliness			1

Blade 3

Item	System / Component	Comments	Photo	Class
13.11	Blade structural condition			1
13.12	Blade connection torque			1
13.13	Blade surface			1
13.14	Blade LPS			
13.15	Blade cleanliness			1

14. Safety System

Item	System / Component	Comments	Photo	Class
14.01	Vibration switch			1
14.02	Overspeed gauge			1
14.03	Fire extinguishers			1
14.04	First aid box			1
14.05	Rescue evacuation rope			1

WIND TURBINE VISUAL INSPECTION	Wind Farm:	Hermanville Wind farm
	Wind Turbine:	T-3

Inspection Data

Wind Turbine (WT):	T-3	*Inspector:*	Malcolm Moore
Wind Farm (WF):	Hermanville Wind farm	*Date:*	April 26, 2022
WF Location:	Souris, PEI, Canada	*From/To:*	9:30 AM 6:00 PM

Wind Turbine Data

WT Make:	Acciona	*Rated Power (kW):*	3,000
WT Model:	AW-3000/116	*Hub Height (m):*	92
Commissioned:	2014	*Rotor Diameter (m):*	116

Wind Turbine Components Identification

	Manufacturer	*Model/Type*	*Serial No.*
Gearbox:	*Winergy*	*PZAB 3535,0*	*NFC-W-100324*
Generator:	*Indar*	*TAR630XA6N60N*	*21505000159*
Blade A:	*Acciona*	*AW56.7*	*90*
Blade B:	*Acciona*	*AW56.7*	*101*
Blade C:	*Acciona*	*AW56.7*	*100*

Inspection Summary

Component Classification

	2	3	4	Total
1. Tower Foundation	1			1
2. Turbine Controls	1			1
3. Service Lift/Climb Assist				
4. Tower Sections	2			2
5. Yaw System	2			2
6. Hydraulic System	2			2
7. Nacelle	2			2

	2	3	4	Total
8. Main Shaft	1			1
9. Gearbox	1	1		2
10. Generator	2			2
11. Top Box Controller				
12. Hub Assembly & Pitch	3	1	1	5
13. Blades	1	1		2
14. Safety System				
Total	18	3	1	22

Visual Inspection Damage Classification

1	**Normal condition**	The component or equipment is typical for its age. May show some signs of wear although it is serviceable and no further action is needed.
2	**Early signs of wear or damage.**	Slightly damaged or worn equipment and/or missing part which presents no potential impact on turbine operation or safety. Despite no urgent corrective action is required, the damaged equipment or component should be repaired or replaced. Meanwhile the equipment or component should be monitored for progression of damage.
3	**Advanced signs of wear or damage.**	Equipment and/or missing part which presents a potential impact to the operation of the turbine and/or safety. Should be scheduled for repair or replacement in short term and no later than next scheduled service. Should be monitored until repairs or replacement takes place.
4	**Failed or missing components.**	The component has failed and/or missing and represents a critical impact to the operation of the turbine and/or a safety hazard. Component and wind turbine if deemed necessary must be taken out of service to prevent further damage. Immediate action to repair or replace is required before returning the component back to service.

1. Tower Foundation

Item	System / Component	Comments	Photo	Class
1.01	Foundation concrete condition			1
1.02	Foundation bolts condition			1
1.03	Tower external wall condition			1
1.04	Tower verticality check			1
1.05	Padmount transformer condition			1
1.06	Tower stairs condition			1

1.07	Tower door condition			1
1.08	Tower door flange and seals			1
1.09	Tower door hinges and lock			1
1.10	Tower door screens and filters			1
1.11	Cleanliness of basement area	Moderate amount of insects and debris in basement		2

2. Turbine Controls

Item	System / Component	Comments	Photo	Class
2.01	Main control cabinet			1
2.02	Control panel	Missing CPU Interface		2
2.03	Cooling system			1
2.04	Converter			1
2.05	Breakers, switches, fuses			1
2.06	Cabling, splices			1
2.07	Grounding			1
2.08	Fans & filters			1
2.09	Light fixtures & LV			1
2.10	HV Switch gear cabinet			1
2.11	HV Switch gear control cable			1
2.12	HV Switch gear gauge check			1

3. Service Lift/Climb Assist

Item	System / Component	Comments	Photo	Class
3.01	Overall condition			1
3.02	Lift entry cage			1
3.03	Functionality of manual descent			1
3.04	Functionality of sensors			1

4. Tower Sections

Base Section

Item	System / Component	Comments	Photo	Class

4.01	Platform condition	Dirt/Oil on diamond plate/platform		2
4.02	Ladder condition			1
4.03	Safety cable condition			1
4.04	Hatch condition			1
4.05	Tower flange condition			1
4.06	Tower walls condition			1
4.07	Bolts condition, ping test			1
4.08	Grounding straps			1
4.09	Light fixtures and LV	Light not functioning		2
4.10	Cabling, Splices			1

Mid Section(s)

Item	System / Component	Comments	Photo	Class
4.11	Platform condition			
4.12	Ladder condition			
4.13	Safety cable condition			
4.14	Hatch condition			
4.15	Tower flange condition			
4.16	Tower walls condition			
4.17	Bolts condition, ping test			
4.18	Grounding straps			
4.19	Light fixtures and LV			
4.20	Cabling, Splices			

Top Section

Item	System / Component	Comments	Photo	Class
4.21	Platform condition			
4.22	Ladder condition			
4.23	Safety cable condition			

4.24	Hatch condition			
4.25	Tower flange condition			
4.26	Tower walls condition			
4.27	Bolts condition, ping test			
4.28	Grounding straps			
4.29	Light fixtures and LV			
4.30	Cabling, Splices			

5. Yaw System

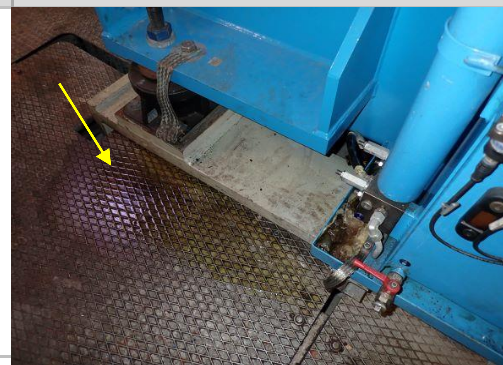
Yaw Deck

Item	System / Component	Comments	Photo	Class
5.01	Platform condition	Multiple loose hardware on platform		2
5.02	Access ladder condition			1
5.03	Hatch condition			1
5.04	Safety cable top assembly			1
5.05	Grounding straps			1
5.06	Light fixtures and LV			1
5.07	Saddle cable condition			1
5.08	Torque check yaw ring			1
5.09	Yaw clamp condition			1
5.10	Yaw clamp manifold lines			1

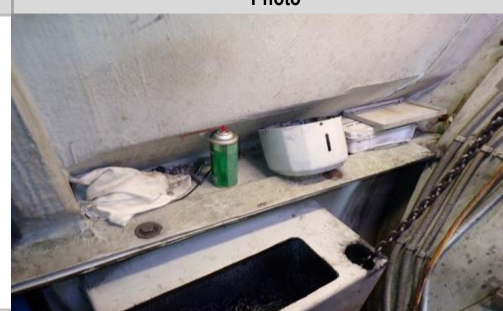
Yaw Components

Item	System / Component	Comments	Photo	Class
5.11	Yaw motors condition			1
5.12	Yaw motors oil level, leakage			1
5.13	Yaw gear condition	Missing yaw motor fan and cover		2
5.14	Yaw gear lubrication			1
5.15	Yaw counter condition			1
5.16	Yaw position sensor condition			1

6. Hydraulic System

Item	System / Component	Comments	Photo	Class
6.01	Hydraulic pump condition	Moderate Oil Puddling under hydraulic system		2
6.02	Accumulator condition			1
6.03	Hoses and couplings	Saturated desiccant filter on Hydraulic system		2
6.04	Oil level, pressure			1
6.05	Radiator condition			1

7. Nacelle

Item	System / Component	Comments	Photo	Class
7.01	Main frame structural condition	Debris and hardware left on nacelle structure		2
7.02	Fiberglass condition, seams			1
7.03	Insulation, soundproofing			1
7.04	Light fixtures and LV			1
7.05	MV Cabling, strain reliefs			1
7.06	Grounding straps			1

Item	System / Component	Comments	Photo	Class
7.07	Nacelle hardware, condition	Hardware and protection coverings cluttering frame and platform		2
7.08	Hub adapter bolts, condition			1
7.09	Rotor lock condition			1
7.10	E-stop functionality			1
7.11	Hoist condition			1
7.12	Hatches, condition			1
7.13	Nacelle tie offs			1
7.14	Anemometer condition			1
7.15	Wind vane condition			1
7.16	Lightning receptor			1
7.17	Met mounting bracket			1

8. Main Shaft

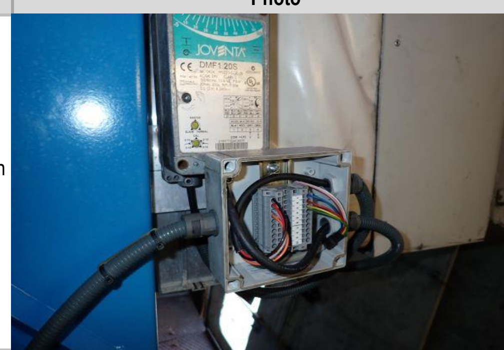
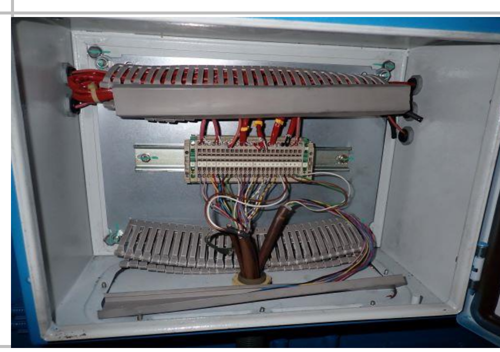
Item	System / Component	Comments	Photo	Class
8.01	Main bearing condition	Missing protection covering/shield		2
8.02	Main bearing mounting hardware			1
8.03	Main shaft condition			1
8.04	Shrink disc condition			1
8.05	Shrink disc mounting hardware			1
8.06	Grease trap			1
8.07	Rotor plate deformation			1
8.08	Rotor plate shield			1

9. Gearbox

Item	System / Component	Comments	Photo	Class
9.01	Gearbox cover condition			1

9.02	Gearbox mounting hardware	Moderate wear on elastomer bearings		2
9.03	Gearbox access ports			1
9.04	Cooling system/circuit			1
9.05	Lubrication pump system			1
9.06	Breather filter condition			1
9.07	Gearbox oil level			1
9.08	Oil filtration system condition			1
9.09	Hoses and couplings			1
9.10	Pitch slip-ring, rotating union	Slip ring missing protection cover and oil forming inside junction box		3

10. Generator

Item	System / Component	Comments	Photo	Class
10.01	Generator cover condition	Generator cooling actuator missing cable junction box cover		2
10.02	Generator feet torque markings			1
10.03	Cooling system/circuit	Generator raceway melting in junction box		2

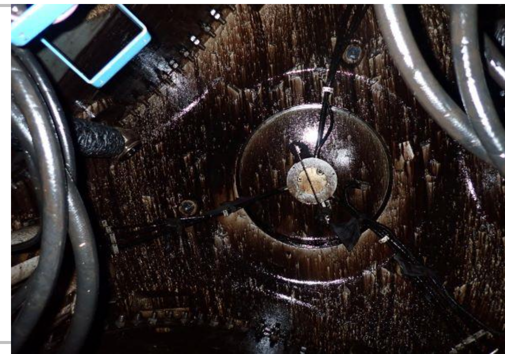
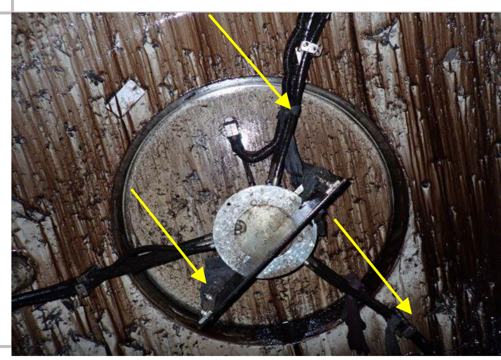
10.04	Lubricant system			1
10.05	Generator bearings			1
10.06	Generator slip ring			1
10.07	MV cable condition, strain relief			1
10.08	Brake disc condition			1
10.09	Brake clamps and calipers			1
10.10	Flexible coupler condition			1
10.11	Flexible coupler torque marks			1
10.12	Flexible coupler safety cover			1

11. Top Box Controller

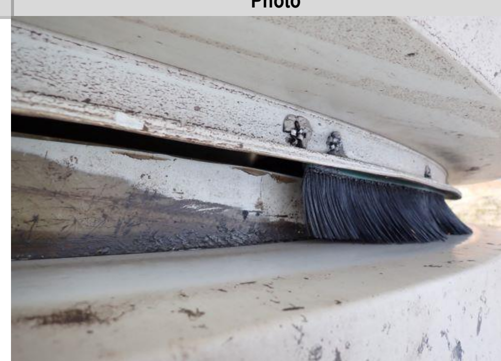
Item	System / Component	Comments	Photo	Class
11.01	Control cabinet condition			1
11.02	Air extraction fan filters			1
11.03	Wire Connections and Cabling			1
11.04	Grounding			1

12. Hub Assembly & Pitch

Item	System / Component	Comments	Photo	Class
12.01	Mounting hardware condition			
12.02	Access hatch condition	Missing both close ot hatches - significant potential for personnel falling into blade		4
12.03	Blade bearing seals			1
12.04	Fiberglass nose cone condition	Missing hardware on blade bearing structure		2
12.05	Cleanliness hub internal			1
12.06	Blade internal protective covers			1
12.07	Rotating union condition			1
12.08	Control box condition			1
12.09	Light fixture and LV			1

12.10	Hydraulic system leaks	Severe grease build up in hub		3
12.11	Pitch accumulator condition			1
12.12	Pitch ram cylinder condition	Exposed pitch ram cylinder		2
12.13	Pitch cylinder bearing condition			1
12.14	Pitch cylinder connection points	Grease saturated rags tied to connection points		2

13. Blades
Blade 1

Item	System / Component	Comments	Photo	Class
13.01	Blade structural condition	Missing debris protection brush		2
13.02	Blade connection torque			1
13.03	Blade surface			1
13.04	Blade LPS			1
13.05	Blade cleanliness			1

Blade 2

Item	System / Component	Comments	Photo	Class
13.06	Blade structural condition			
13.07	Blade connection torque			
13.08	Blade surface			
13.09	Blade LPS			
13.10	Blade cleanliness			

Blade 3

Item	System / Component	Comments	Photo	Class
13.11	Blade structural condition			1
13.12	Blade connection torque			1
13.13	Blade surface			1
13.14	Blade LPS	Disconnected/damaged LPS cable		3
13.15	Blade cleanliness			1

14. Safety System

Item	System / Component	Comments	Photo	Class
14.01	Vibration switch			1
14.02	Overspeed gauge			1
14.03	Fire extinguishers			1
14.04	First aid box			1
14.05	Rescue evacuation rope			1

WIND TURBINE VISUAL INSPECTION	Wind Farm:	Hermanville Wind farm
	Wind Turbine:	T-6

Inspection Data

Wind Turbine (WT):	T-6	*Inspector:*	Malcolm Moore	
Wind Farm (WF):	Hermanville Wind farm	*Date:*	April 28, 2022	
WF Location:	Souris, PEI, Canada	*From/To:*	7:45 AM	9:05 AM

Wind Turbine Data

WT Make:	Acciona	*Rated Power (kW):*	3,000
WT Model:	AW-3000/116	*Hub Height (m):*	92
Commissioned:	2014	*Rotor Diameter (m):*	116

Wind Turbine Components Identification

	Manufacturer	*Model/Type*	*Serial No.*
Gearbox:	*Winergy*	*PZAB 3535,0*	*NFC-W-100327*
Generator:	*Indar*	*TAR630XA6N60N*	*21516000006*
Blade A:	*Acciona*	*AW56.7*	*91*
Blade B:	*Acciona*	*AW56.7*	*485*
Blade C:	*Acciona*	*AW56.7*	*95*

Inspection Summary

Component Classification

	2	3	4	Total
1. Tower Foundation	3			3
2. Turbine Controls	5			5
3. Service Lift/Climb Assist				
4. Tower Sections	1			1
5. Yaw System	1	1		2
6. Hydraulic System				
7. Nacelle	5			5

	2	3	4	Total
8. Main Shaft		1	2	3
9. Gearbox	3			3
10. Generator	1		2	3
11. Top Box Controller				
12. Hub Assembly & Pitch				
13. Blades				
14. Safety System		1		1
Total	19	3	4	26

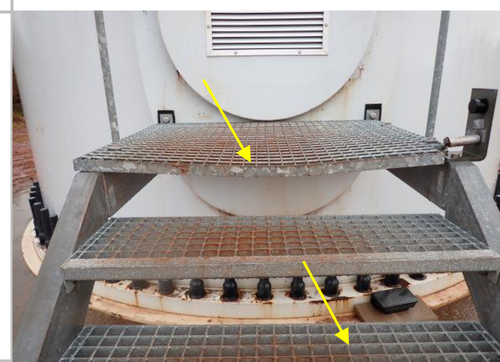
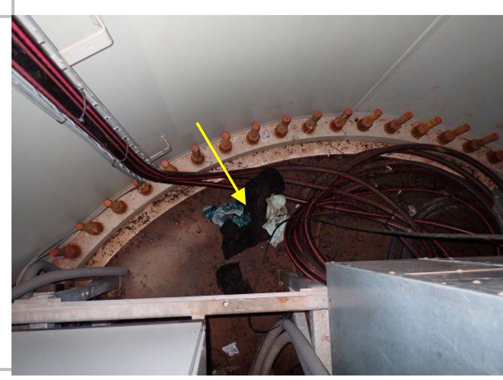
Visual Inspection Damage Classification

1	Normal condition	The component or equipment is typical for its age. May show some signs of wear although it is serviceable and no further action is needed.
2	Early signs of wear or damage.	Slightly damaged or worn equipment and/or missing part which presents no potential impact on turbine operation or safety. Despite no urgent corrective action is required, the damaged equipment or component should be repaired or replaced. Meanwhile the equipment or component should be monitored for progression of damage.
3	Advanced signs of wear or damage.	Equipment and/or missing part which presents a potential impact to the operation of the turbine and/or safety. Should be scheduled for repair or replacement in short term and no later than next scheduled service. Should be monitored until repairs or replacement takes place.
4	Failed or missing components.	The component has failed and/or missing and represents a critical impact to the operation of the turbine and/or a safety hazard. Component and wind turbine if deemed necessary must be taken out of service to prevent further damage. Immediate action to repair or replace is required before returning the component back to service.

1. Tower Foundation

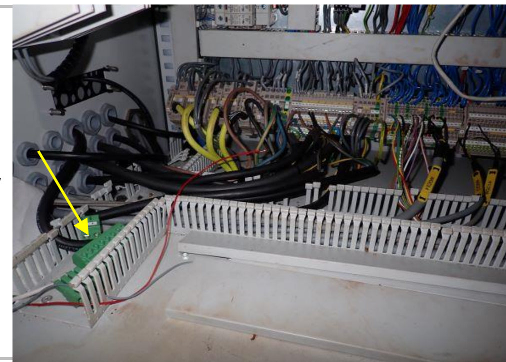
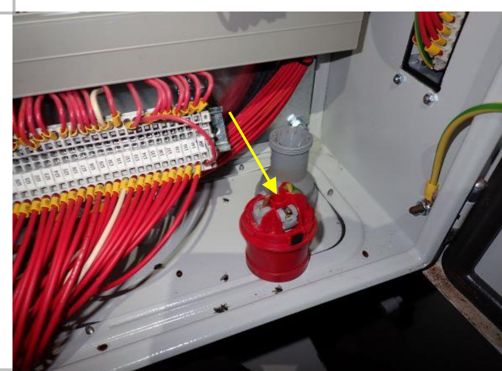
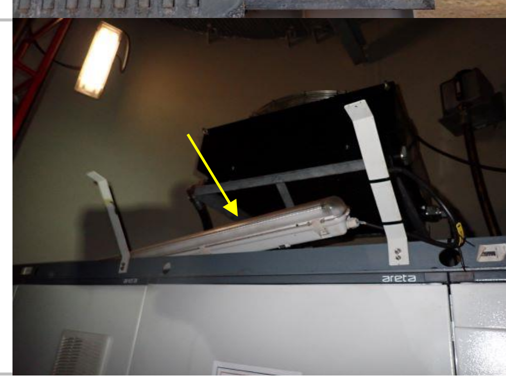
Item	System / Component	Comments	Photo	Class

WIND TURBINE VISUAL INSPECTION	Wind Farm:	Hermanville Wind farm
	Wind Turbine:	T-6

1.01	Foundation concrete condition	Moderate corrosion and paint chipping around bases of foundation bolts		2
1.02	Foundation bolts condition			1
1.03	Tower external wall condition			1
1.04	Tower verticality check			1
1.05	Padmount transformer condition			1
1.06	Tower stairs condition	Mild deforming of top stair landing		2
1.07	Tower door condition			1
1.08	Tower door flange and seals			1
1.09	Tower door hinges and lock			1
1.10	Tower door screens and filters			1
1.11	Cleanliness of basement area	Saturated rags and insects covering basement floor and cables		2

2. Turbine Controls

Item	System / Component	Comments	Photo	Class

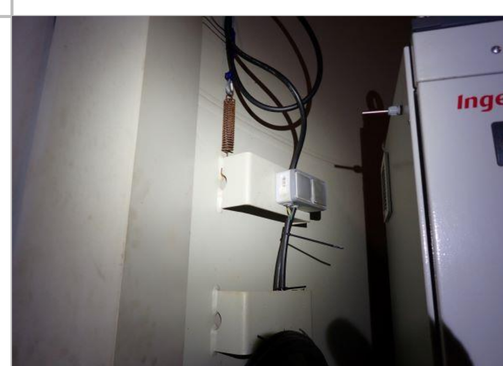
2.01	Main control cabinet	Unused components and cables left on raceway		2
2.02	Control panel			1
2.03	Cooling system			1
2.04	Converter			1
2.05	Breakers, switches, fuses			1
2.06	Cabling, splices	Unused plug cut and left in cabinet		2
2.07	Grounding			1
2.08	Fans & filters	Door filters need replaced		2
2.09	Light fixtures & LV	Light not functioning		2

2.10	HV Switch gear cabinet	Missing hardware		2
2.11	HV Switch gear control cable			
2.12	HV Switch gear gauge check			

3. Service Lift/Climb Assist

Item	System / Component	Comments	Photo	Class
3.01	Overall condition			
3.02	Lift entry cage			
3.03	Functionality of manual descent			
3.04	Functionality of sensors			

4. Tower Sections
Base Section

Item	System / Component	Comments	Photo	Class
4.01	Platform condition			1
4.02	Ladder condition			1
4.03	Safety cable condition			1
4.04	Hatch condition			1
4.05	Tower flange condition			1
4.06	Tower walls condition			1
4.07	Bolts condition, ping test			1
4.08	Grounding straps			1
4.09	Light fixtures and LV	Tower lighting does not function		2
4.10	Cabling, Splices			1

Mid Section(s)

Item	System / Component	Comments	Photo	Class
4.11	Platform condition			
4.12	Ladder condition			
4.13	Safety cable condition			
4.14	Hatch condition			
4.15	Tower flange condition			

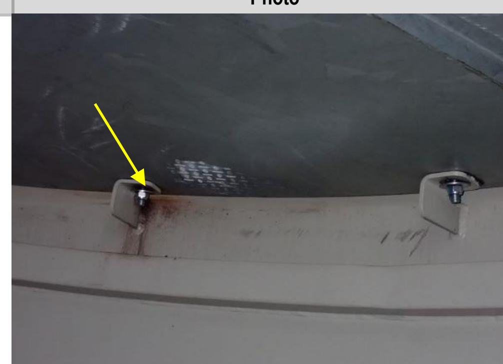
4.16	Tower walls condition			
4.17	Bolts condition, ping test			
4.18	Grounding straps			
4.19	Light fixtures and LV			
4.20	Cabling, Splices			

Top Section

Item	System / Component	Comments	Photo	Class
4.21	Platform condition			
4.22	Ladder condition			
4.23	Safety cable condition			
4.24	Hatch condition			
4.25	Tower flange condition			
4.26	Tower walls condition			
4.27	Bolts condition, ping test			
4.28	Grounding straps			
4.29	Light fixtures and LV			
4.30	Cabling, Splices			

5. Yaw System

Yaw Deck

Item	System / Component	Comments	Photo	Class
5.01	Platform condition	Loose hardware on bottom side of platform		2
5.02	Access ladder condition			1
5.03	Hatch condition			1
5.04	Safety cable top assembly			1
5.05	Grounding straps			1
5.06	Light fixtures and LV			1
5.07	Saddle cable condition			1
5.08	Torque check yaw ring			1
5.09	Yaw clamp condition			1
5.10	Yaw clamp manifold lines			1

Yaw Components

Item	System / Component	Comments	Photo	Class

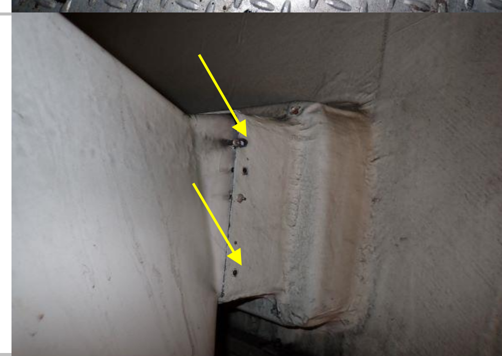
Item	System / Component	Comments	Photo	Class
5.11	Yaw motors condition	Missing motor cover exposing rotor windings		3
5.12	Yaw motors oil level, leakage			1
5.13	Yaw gear condition			1
5.14	Yaw gear lubrication			1
5.15	Yaw counter condition			1
5.16	Yaw position sensor condition			1

6. Hydraulic System

Item	System / Component	Comments	Photo	Class
6.01	Hydraulic pump condition			1
6.02	Accumulator condition			1
6.03	Hoses and couplings			1
6.04	Oil level, pressure			1
6.05	Radiator condition			1

7. Nacelle

Item	System / Component	Comments	Photo	Class
7.01	Main frame structural condition	Moderate corrosion near footing of generator		2
7.02	Fiberglass condition, seams	Hardware left on fiberglass nacelle housing		2
7.03	Insulation, soundproofing			1

7.04	Light fixtures and LV	Light not functioning		2
7.05	MV Cabling, strain reliefs			1
7.06	Grounding straps			1
7.07	Nacelle hardware, condition	Moderate corrosion on platform bolts of nacelle		2
7.08	Hub adapter bolts, condition	Nacelle Fiberglass structure missing hardware		2
7.09	Rotor lock condition			1
7.10	E-stop functionality			1
7.11	Hoist condition			1
7.12	Hatches, condition			1
7.13	Nacelle tie offs			1
7.14	Anemometer condition			1
7.15	Wind vane condition			1
7.16	Lightning receptor			1
7.17	Met mounting bracket			1

8. Main Shaft

Item	System / Component	Comments	Photo	Class

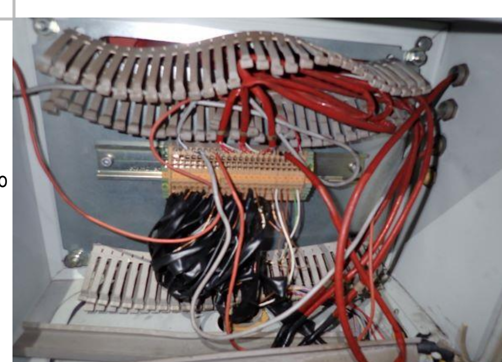
8.01	Main bearing condition	Failed main bearing - replacement required		4
8.02	Main bearing mounting hardware	Loose and missing hardware		3
8.03	Main shaft condition			1
8.04	Shrink disc condition			1
8.05	Shrink disc mounting hardware			1
8.06	Grease trap	Moderate mettalic wear in grease, indicative of failed bearing		4
8.07	Rotor plate deformation			1
8.08	Rotor plate shield			1

9. Gearbox

Item	System / Component	Comments	Photo	Class
9.01	Gearbox cover condition	Moderate corrosion at foot of gearbox		2

9.02	Gearbox mounting hardware	Moderate wear on elastomer bearings		2
9.03	Gearbox access ports			1
9.04	Cooling system/circuit			1
9.05	Lubrication pump system			1
9.06	Breather filter condition			1
9.07	Gearbox oil level			1
9.08	Oil filtration system condition	Oversaturated oil breather filter		2
9.09	Hoses and couplings			1
9.10	Pitch slip-ring, rotating union			1

10. Generator

Item	System / Component	Comments	Photo	Class
10.01	Generator cover condition			1
10.02	Generator feet torque markings			1
10.03	Cooling system/circuit			1
10.04	Lubricant system			1
10.05	Generator bearings			1
10.06	Generator slip ring			1
10.07	MV cable condition, strain relief	Melting of raceway and signs of excessive heat to cables		2
10.08	Brake disc condition			1
10.09	Brake clamps and calipers			1

10.10	Flexible coupler condition	Not Installed		4
10.11	Flexible coupler torque marks			1
10.12	Flexible coupler safety cover	Protection cover missing with hardware; not installed		4

11. Top Box Controller

Item	System / Component	Comments	Photo	Class
11.01	Control cabinet condition			1
11.02	Air extraction fan filters			1
11.03	Wire Connections and Cabling			1
11.04	Grounding			1

12. Hub Assembly & Pitch

Item	System / Component	Comments	Photo	Class
12.01	Mounting hardware condition	Not inspected due to turbine condition		
12.02	Access hatch condition			
12.03	Blade bearing seals			
12.04	Fiberglass nose cone condition			
12.05	Cleanliness hub internal			
12.06	Blade internal protective covers			
12.07	Rotating union condition			
12.08	Control box condition			
12.09	Light fixture and LV			
12.10	Hydraulic system leaks			
12.11	Pitch accumulator condition			
12.12	Pitch ram cylinder condition			
12.13	Pitch cylinder bearing condition			
12.14	Pitch cylinder connection points			

13. Blades
Blade 1

Item	System / Component	Comments	Photo	Class
13.01	Blade structural condition	Not inspected due to turbine condition		

13.02	Blade connection torque			
13.03	Blade surface			
13.04	Blade LPS			
13.05	Blade cleanliness			

Blade 2

Item	System / Component	Comments	Photo	Class
13.06	Blade structural condition	Not inspected due to turbine condition		
13.07	Blade connection torque			
13.08	Blade surface			
13.09	Blade LPS			
13.10	Blade cleanliness			

Blade 3

Item	System / Component	Comments	Photo	Class
13.11	Blade structural condition	Not inspected due to turbine condition		
13.12	Blade connection torque			
13.13	Blade surface			
13.14	Blade LPS			
13.15	Blade cleanliness			

14. Safety System

Item	System / Component	Comments	Photo	Class
14.01	Vibration switch	Harting plug on PCH sensor secured with zip ties and electrical tape		3
14.02	Overspeed gauge			1
14.03	Fire extinguishers			1
14.04	First aid box			1
14.05	Rescue evacuation rope			1

WIND TURBINE VISUAL INSPECTION	Wind Farm:	Hermanville Wind farm
	Wind Turbine:	T-7

Inspection Data

Wind Turbine (WT):	T-7	*Inspector:*	Malcolm Moore
Wind Farm (WF):	Hermanville Wind farm	*Date:*	April 28, 2022
WF Location:	Souris, PEI, Canada	*From/To:*	10:15 AM 11:15 AM

Wind Turbine Data

WT Make:	Acciona	*Rated Power (kW):*	3,000
WT Model:	AW-3000/116	*Hub Height (m):*	92
Commissioned:	2014	*Rotor Diameter (m):*	116

Wind Turbine Components Identification

	Manufacturer	*Model/Type*	*Serial No.*
Gearbox:	*Winergy*	*PZAB 3535,0*	*NFC-4851057-0210-1*
Generator:	*Indar*	*TAR630XA6B60N*	*21516000004*
Blade A:	*Acciona*	*AW56.7*	*111*
Blade B:	*Acciona*	*AW56.7*	*110*
Blade C:	*Acciona*	*AW56.7*	*112*

Inspection Summary

Component Classification

	2	3	4	Total
1. Tower Foundation	1			1
2. Turbine Controls	1			1
3. Service Lift/Climb Assist				
4. Tower Sections	1			1
5. Yaw System	4	1		5
6. Hydraulic System	2			2
7. Nacelle				

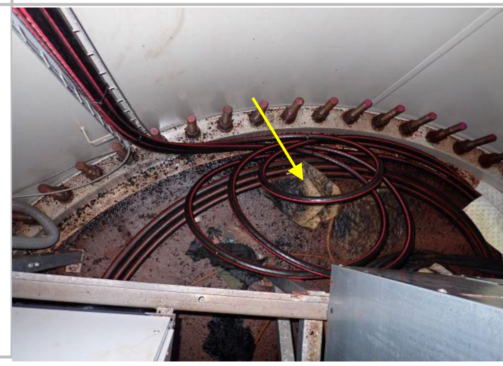
	2	3	4	Total
8. Main Shaft				
9. Gearbox	1			1
10. Generator	3			3
11. Top Box Controller	1			1
12. Hub Assembly & Pitch				
13. Blades				
14. Safety System		1		1
Total	14	2	0	16

Visual Inspection Damage Classification

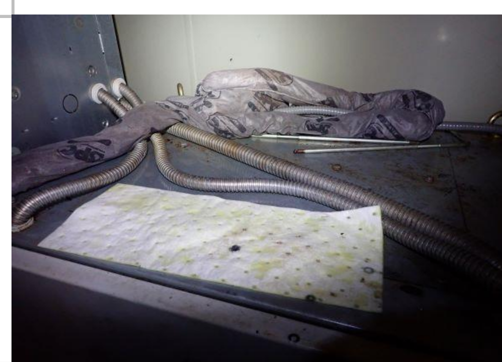
1	Normal condition	The component or equipment is typical for its age. May show some signs of wear although it is serviceable and no further action is needed.
2	Early signs of wear or damage.	Slightly damaged or worn equipment and/or missing part which presents no potential impact on turbine operation or safety. Despite no urgent corrective action is required, the damaged equipment or component should be repaired or replaced. Meanwhile the equipment or component should be monitored for progression of damage.
3	Advanced signs of wear or damage.	Equipment and/or missing part which presents a potential impact to the operation of the turbine and/or safety. Should be scheduled for repair or replacement in short term and no later than next scheduled service. Should be monitored until repairs or replacement takes place.
4	Failed or missing components.	The component has failed and/or missing and represents a critical impact to the operation of the turbine and/or a safety hazard. Component and wind turbine if deemed necessary must be taken out of service to prevent further damage. Immediate action to repair or replace is required before returning the component back to service.

1. Tower Foundation

Item	System / Component	Comments	Photo	Class
1.01	Foundation concrete condition			1
1.02	Foundation bolts condition			1
1.03	Tower external wall condition			1
1.04	Tower verticality check			1
1.05	Padmount transformer condition			1
1.06	Tower stairs condition			1
1.07	Tower door condition			1
1.08	Tower door flange and seals			1

1.09	Tower door hinges and lock			1
1.10	Tower door screens and filters			1
1.11	Cleanliness of basement area	Saturated rags and severe oil leakage on basement floor		2

2. Turbine Controls

Item	System / Component	Comments	Photo	Class
2.01	Main control cabinet			1
2.02	Control panel			1
2.03	Cooling system			1
2.04	Converter			1
2.05	Breakers, switches, fuses			1
2.06	Cabling, splices			1
2.07	Grounding			1
2.08	Fans & filters			1
2.09	Light fixtures & LV			1
2.10	HV Switch gear cabinet	Saturated pig mat on cabinet		2
2.11	HV Switch gear control cable			1
2.12	HV Switch gear gauge check			1

3. Service Lift/Climb Assist

Item	System / Component	Comments	Photo	Class
3.01	Overall condition			1
3.02	Lift entry cage			1
3.03	Functionality of manual descent			1
3.04	Functionality of sensors			1

4. Tower Sections
Base Section

Item	System / Component	Comments	Photo	Class

4.01	Platform condition	Saturated pig mat and trip hazards on platform		2
4.02	Ladder condition			1
4.03	Safety cable condition			1
4.04	Hatch condition			1
4.05	Tower flange condition			1
4.06	Tower walls condition			1
4.07	Bolts condition, ping test			1
4.08	Grounding straps			1
4.09	Light fixtures and LV			1
4.10	Cabling, Splices			1

Mid Section(s)

Item	System / Component	Comments	Photo	Class
4.11	Platform condition			
4.12	Ladder condition			
4.13	Safety cable condition			
4.14	Hatch condition			
4.15	Tower flange condition			
4.16	Tower walls condition			
4.17	Bolts condition, ping test			
4.18	Grounding straps			
4.19	Light fixtures and LV			
4.20	Cabling, Splices			

Top Section

Item	System / Component	Comments	Photo	Class
4.21	Platform condition			1
4.22	Ladder condition			1
4.23	Safety cable condition			1
4.24	Hatch condition			1
4.25	Tower flange condition			1
4.26	Tower walls condition			1
4.27	Bolts condition, ping test			1
4.28	Grounding straps			1
4.29	Light fixtures and LV			1
4.30	Cabling, Splices			1

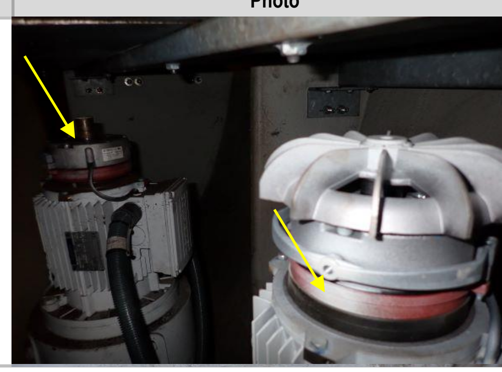
5. Yaw System

Yaw Deck

Item	System / Component	Comments	Photo	Class

5.01	Platform condition	Loose/damaged bolt on platform		2
5.02	Access ladder condition			1
5.03	Hatch condition			1
5.04	Safety cable top assembly			1
5.05	Grounding straps			1
5.06	Light fixtures and LV	Outlet missing protection cover		2
5.07	Saddle cable condition	Saturated pig mat dripping on cables		2
5.08	Torque check yaw ring			1
5.09	Yaw clamp condition			1
5.10	Yaw clamp manifold lines			1

Yaw Components

Item	System / Component	Comments	Photo	Class
5.11	Yaw motors condition	Missing protection cover and cooling fan		2

5.12	Yaw motors oil level, leakage	Severe grease leakage on nacelle structure/housing		3
5.13	Yaw gear condition			
5.14	Yaw gear lubrication			
5.15	Yaw counter condition			
5.16	Yaw position sensor condition			

6. Hydraulic System

Item	System / Component	Comments	Photo	Class
6.01	Hydraulic pump condition	Moderate corrosion on hydraulic block; mild leakage		2
6.02	Accumulator condition			1
6.03	Hoses and couplings			1
6.04	Oil level, pressure	Saturated desiccant breather filter		2
6.05	Radiator condition			1

7. Nacelle

Item	System / Component	Comments	Photo	Class
7.01	Main frame structural condition			1
7.02	Fiberglass condition, seams			1
7.03	Insulation, soundproofing			1
7.04	Light fixtures and LV			1
7.05	MV Cabling, strain reliefs			1
7.06	Grounding straps			1
7.07	Nacelle hardware, condition			1

7.08	Hub adapter bolts, condition			1
7.09	Rotor lock condition			1
7.10	E-stop functionality			1
7.11	Hoist condition			1
7.12	Hatches, condition			1
7.13	Nacelle tie offs			1
7.14	Anemometer condition			1
7.15	Wind vane condition			1
7.16	Lightning receptor			1
7.17	Met mounting bracket			1

8. Main Shaft

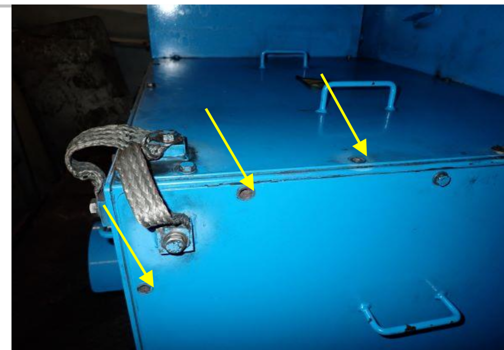
Item	System / Component	Comments	Photo	Class
8.01	Main bearing condition			1
8.02	Main bearing mounting hardware			1
8.03	Main shaft condition			1
8.04	Shrink disc condition			1
8.05	Shrink disc mounting hardware			1
8.06	Grease trap			1
8.07	Rotor plate deformation			1
8.08	Rotor plate shield			1

9. Gearbox

Item	System / Component	Comments	Photo	Class
9.01	Gearbox cover condition			1
9.02	Gearbox mounting hardware	Elastomer bearing wear - moderate		2
9.03	Gearbox access ports			1
9.04	Cooling system/circuit			1
9.05	Lubrication pump system			1
9.06	Breather filter condition			1
9.07	Gearbox oil level			1
9.08	Oil filtration system condition			1
9.09	Hoses and couplings			1
9.10	Pitch slip-ring, rotating union			1

10. Generator

Item	System / Component	Comments	Photo	Class

10.01	Generator cover condition	Missing Hardware		2
10.02	Generator feet torque markings	Loose Hardware left at foot of generator		2
10.03	Cooling system/circuit			1
10.04	Lubricant system			1
10.05	Generator bearings			1
10.06	Generator slip ring			1
10.07	MV cable condition, strain relief	Melting of raceway and sign of excessive heat to wiring		2
10.08	Brake disc condition			1
10.09	Brake clamps and calipers			1
10.10	Flexible coupler condition			1
10.11	Flexible coupler torque marks			1
10.12	Flexible coupler safety cover			1

11. Top Box Controller

Item	System / Component	Comments	Photo	Class

Item	System / Component	Comments	Photo	Class
11.01	Control cabinet condition	Top box mounting bushing - excessive wear		2
11.02	Air extraction fan filters			1
11.03	Wire Connections and Cabling			1
11.04	Grounding			1

12. Hub Assembly & Pitch

Item	System / Component	Comments	Photo	Class
12.01	Mounting hardware condition			1
12.02	Access hatch condition			1
12.03	Blade bearing seals			1
12.04	Fiberglass nose cone condition			1
12.05	Cleanliness hub internal			1
12.06	Blade internal protective covers			1
12.07	Rotating union condition			1
12.08	Control box condition			1
12.09	Light fixture and LV			1
12.10	Hydraulic system leaks			1
12.11	Pitch accumulator condition			1
12.12	Pitch ram cylinder condition			1
12.13	Pitch cylinder bearing condition			1
12.14	Pitch cylinder connection points			1

13. Blades

Blade 1

Item	System / Component	Comments	Photo	Class
13.01	Blade structural condition			
13.02	Blade connection torque			
13.03	Blade surface			
13.04	Blade LPS			
13.05	Blade cleanliness			

Blade 2

Item	System / Component	Comments	Photo	Class
13.06	Blade structural condition			
13.07	Blade connection torque			
13.08	Blade surface			
13.09	Blade LPS			
13.10	Blade cleanliness			

Blade 3

Item	System / Component	Comments	Photo	Class
13.11	Blade structural condition			
13.12	Blade connection torque			
13.13	Blade surface			
13.14	Blade LPS			
13.15	Blade cleanliness			

14. Safety System

Item	System / Component	Comments	Photo	Class
14.01	Vibration switch	Ziptied harting plug on PCH sensor		3
14.02	Overspeed gauge			1
14.03	Fire extinguishers			1
14.04	First aid box			1
14.05	Rescue evacuation rope			1

WIND TURBINE VISUAL INSPECTION	Wind Farm:	Hermanville Wind farm	DNV
	Wind Turbine:	T-8	

Inspection Data

Wind Turbine (WT):	T-8	*Inspector:*	Malcolm Moore
Wind Farm (WF):	Hermanville Wind farm	*Date:*	April 28, 2022
WF Location:	Souris, PEI, Canada	*From/To:*	9:00 AM 10:00 AM

Wind Turbine Data

WT Make:	Acciona	*Rated Power (kW):*	3,000
WT Model:	AW-3000/116	*Hub Height (m):*	92
Commissioned: 2012	2014	*Rotor Diameter (m):*	116

Wind Turbine Components Identification

	Manufacturer	*Model/Type*	*Serial No.*
Gearbox:	*Winergy*	*PZAB 3535,0*	*NFC-W-100331*
Generator:	*Indar*	*TAR630XA6N60N*	*21516000011*
Blade A:	*Acciona*	*AW56.7*	*108*
Blade B:	*Acciona*	*AW56.7*	*488*
Blade C:	*Acciona*	*AW56.7*	*486*

Inspection Summary

Component Classification

	2	3	4	Total
1. Tower Foundation	2	1		3
2. Turbine Controls	3	1		4
3. Service Lift/Climb Assist				
4. Tower Sections		1		1
5. Yaw System	2	1		3
6. Hydraulic System	2			2
7. Nacelle	1			1

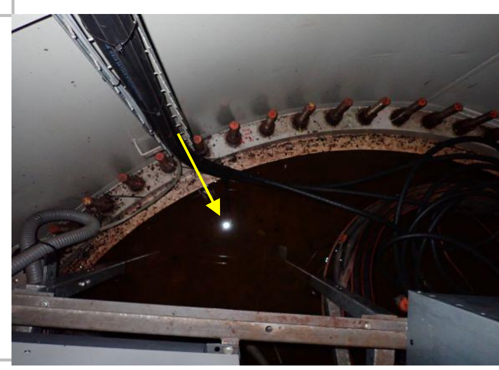
	2	3	4	Total
8. Main Shaft				
9. Gearbox	2			2
10. Generator	1		1	2
11. Top Box Controller	1			1
12. Hub Assembly & Pitch	1			1
13. Blades	1	1	1	3
14. Safety System				
Total	16	5	2	23

Visual Inspection Damage Classification

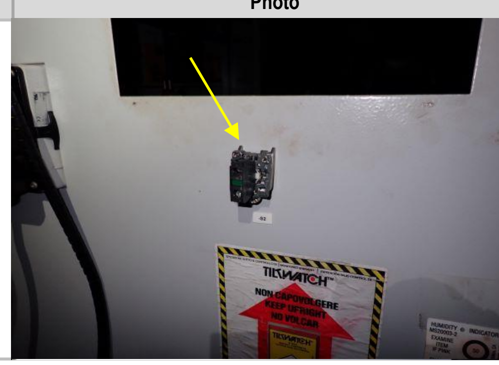
1	**Normal condition**	The component or equipment is typical for its age. May show some signs of wear although it is serviceable and no further action is needed.
2	**Early signs of wear or damage.**	Slightly damaged or worn equipment and/or missing part which presents no potential impact on turbine operation or safety. Despite no urgent corrective action is required, the damaged equipment or component should be repaired or replaced. Meanwhile the equipment or component should be monitored for progression of damage.
3	**Advanced signs of wear or damage.**	Equipment and/or missing part which presents a potential impact to the operation of the turbine and/or safety. Should be scheduled for repair or replacement in short term and no later than next scheduled service. Should be monitored until repairs or replacement takes place.
4	**Failed or missing components.**	The component has failed and/or missing and represents a critical impact to the operation of the turbine and/or a safety hazard. Component and wind turbine if deemed necessary must be taken out of service to prevent further damage. Immediate action to repair or replace is required before returning the component back to service.

1. Tower Foundation

Item	System / Component	Comments	Photo	Class
1.01	Foundation concrete condition			

1.02	Foundation bolts condition	Moderate corrosion and aint chipping near base of foundation bolts		2
1.03	Tower external wall condition			1
1.04	Tower verticality check			1
1.05	Padmount transformer condition			1
1.06	Tower stairs condition	Mild deforming of stair top step		2
1.07	Tower door condition			1
1.08	Tower door flange and seals			1
1.09	Tower door hinges and lock			1
1.10	Tower door screens and filters			1
1.11	Cleanliness of basement area	Severe Flooding/oil in basement floor		3

2. Turbine Controls

Item	System / Component	Comments	Photo	Class
2.01	Main control cabinet	Key operation connection not connected		3

2.02	Control panel	Missing CPU interface		2
2.03	Cooling system			1
2.04	Converter			1
2.05	Breakers, switches, fuses			1
2.06	Cabling, splices			1
2.07	Grounding			1
2.08	Fans & filters			1
2.09	Light fixtures & LV	Cabinet light not functioning		2
2.10	HV Switch gear cabinet	Cabinet missing hardware		2
2.11	HV Switch gear control cable			1
2.12	HV Switch gear gauge check			1

3. Service Lift/Climb Assist

Item	System / Component	Comments	Photo	Class
3.01	Overall condition			1
3.02	Lift entry cage			1
3.03	Functionality of manual descent			1
3.04	Functionality of sensors			1

4. Tower Sections
Base Section

Item	System / Component	Comments	Photo	Class
4.01	Platform condition			1
4.02	Ladder condition			1

4.03	Safety cable condition			1
4.04	Hatch condition			1
4.05	Tower flange condition			1
4.06	Tower walls condition			1
4.07	Bolts condition, ping test			1
4.08	Grounding straps			1
4.09	Light fixtures and LV			1
4.10	Cabling, Splices			1

Mid Section(s)

Item	System / Component	Comments	Photo	Class
4.11	Platform condition			
4.12	Ladder condition			
4.13	Safety cable condition			
4.14	Hatch condition			
4.15	Tower flange condition			
4.16	Tower walls condition			
4.17	Bolts condition, ping test			
4.18	Grounding straps			
4.19	Light fixtures and LV			
4.20	Cabling, Splices			

Top Section

Item	System / Component	Comments	Photo	Class
4.21	Platform condition			
4.22	Ladder condition			
4.23	Safety cable condition			
4.24	Hatch condition			
4.25	Tower flange condition			
4.26	Tower walls condition			
4.27	Bolts condition, ping test			
4.28	Grounding straps			
4.29	Light fixtures and LV			
4.30	Cabling, Splices	Damaged cable halo/spacer		3

5. Yaw System
Yaw Deck

Item	System / Component	Comments	Photo	Class
5.01	Platform condition			1
5.02	Access ladder condition			1

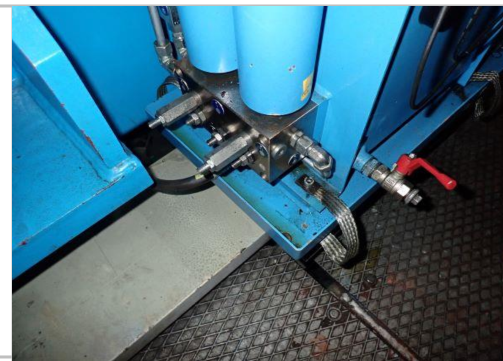
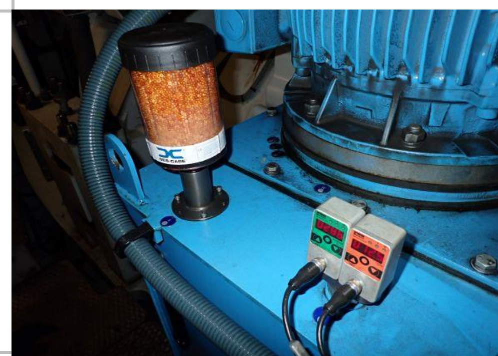
5.03	Hatch condition			1
5.04	Safety cable top assembly			1
5.05	Grounding straps			1
5.06	Light fixtures and LV			1
5.07	Saddle cable condition			1
5.08	Torque check yaw ring			1
5.09	Yaw clamp condition			1
5.10	Yaw clamp manifold lines			1

Yaw Components

Item	System / Component	Comments	Photo	Class
5.11	Yaw motors condition	Missing protection cover hardware		2
5.12	Yaw motors oil level, leakage	moderate leakage from yaw motor		2
5.13	Yaw gear condition	Severe oil leak near yaw gear teeth		3
5.14	Yaw gear lubrication			
5.15	Yaw counter condition			
5.16	Yaw position sensor condition			

6. Hydraulic System

Item	System / Component	Comments	Photo	Class

6.01	Hydraulic pump condition	Mild oil leakage pooling in tray		2
6.02	Accumulator condition			1
6.03	Hoses and couplings			1
6.04	Oil level, pressure	Mild oil leakage pooling in tray		2
6.05	Radiator condition			1

7. Nacelle

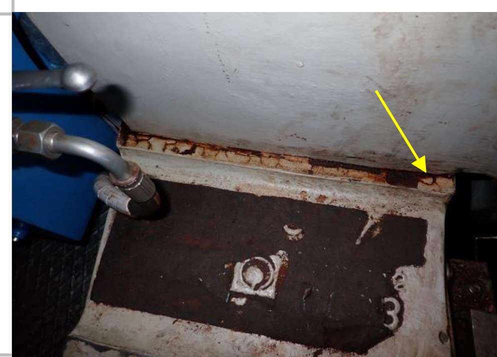
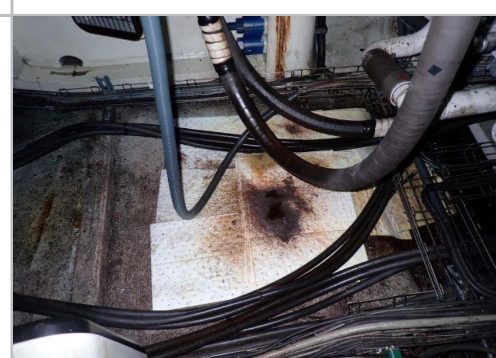
Item	System / Component	Comments	Photo	Class
7.01	Main frame structural condition			1
7.02	Fiberglass condition, seams	Saturated rags and fire extuingusher left on nacelle fiberglass		2
7.03	Insulation, soundproofing			1
7.04	Light fixtures and LV			1
7.05	MV Cabling, strain reliefs			1
7.06	Grounding straps			1
7.07	Nacelle hardware, condition			1
7.08	Hub adapter bolts, condition			1
7.09	Rotor lock condition			1
7.10	E-stop functionality			1
7.11	Hoist condition			1
7.12	Hatches, condition			1
7.13	Nacelle tie offs			1
7.14	Anemometer condition			1
7.15	Wind vane condition			1

7.16	Lightning receptor			1
7.17	Met mounting bracket			1

8. Main Shaft

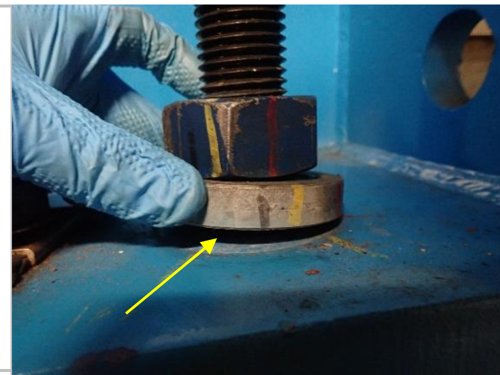
Item	System / Component	Comments	Photo	Class
8.01	Main bearing condition			1
8.02	Main bearing mounting hardware			1
8.03	Main shaft condition			1
8.04	Shrink disc condition			1
8.05	Shrink disc mounting hardware			1
8.06	Grease trap			1
8.07	Rotor plate deformation			1
8.08	Rotor plate shield			1

9. Gearbox

Item	System / Component	Comments	Photo	Class
9.01	Gearbox cover condition			1
9.02	Gearbox mounting hardware	Moderate corrosion and paint chipping near feet of gearbox		2
9.03	Gearbox access ports			1
9.04	Cooling system/circuit			1
9.05	Lubrication pump system			1
9.06	Breather filter condition			1
9.07	Gearbox oil level	Saturated pigmat under gearbox		2
9.08	Oil filtration system condition			1
9.09	Hoses and couplings			1
9.10	Pitch slip-ring, rotating union			1

10. Generator

Item	System / Component	Comments	Photo	Class
10.01	Generator cover condition			1

10.02	Generator feet torque markings	Loose hardware at foot of generator - generator foot loosened by hand. Re-torque required.		4
10.03	Cooling system/circuit			1
10.04	Lubricant system			2
10.05	Generator bearings			1
10.06	Generator slip ring			1
10.07	MV cable condition, strain relief			1
10.08	Brake disc condition			1
10.09	Brake clamps and calipers			1
10.10	Flexible coupler condition			1
10.11	Flexible coupler torque marks			1
10.12	Flexible coupler safety cover			1

11. Top Box Controller

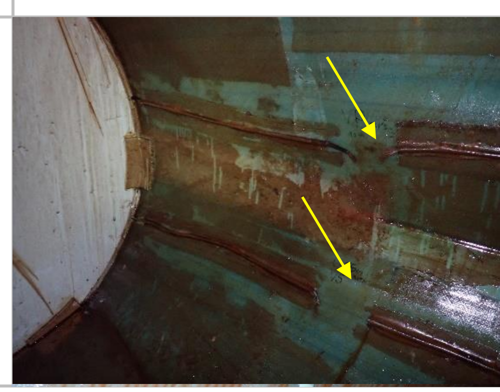
Item	System / Component	Comments	Photo	Class
11.01	Control cabinet condition	Top box mount/bushings damaged		2
11.02	Air extraction fan filters			1
11.03	Wire Connections and Cabling			1
11.04	Grounding			1

12. Hub Assembly & Pitch

Item	System / Component	Comments	Photo	Class
12.01	Mounting hardware condition			1
12.02	Access hatch condition			1
12.03	Blade bearing seals			1
12.04	Fiberglass nose cone condition			1

12.05	Cleanliness hub internal	Missing blade protection/collar near hub entry		2
12.06	Blade internal protective covers			1
12.07	Rotating union condition			1
12.08	Control box condition			1
12.09	Light fixture and LV			1
12.10	Hydraulic system leaks			1
12.11	Pitch accumulator condition			1
12.12	Pitch ram cylinder condition			1
12.13	Pitch cylinder bearing condition			1
12.14	Pitch cylinder connection points			1

13. Blades
Blade 1

Item	System / Component	Comments	Photo	Class
13.01	Blade structural condition	Chordwise TE cracking at R13		4
13.02	Blade connection torque			1
13.03	Blade surface			1
13.04	Blade LPS	Blade LPS disconnected/damaged		3

13.05	Blade cleanliness	Blade internal saturated with oil/grease		2

Blade 2

Item	System / Component	Comments	Photo	Class
13.06	Blade structural condition			
13.07	Blade connection torque			
13.08	Blade surface			
13.09	Blade LPS			
13.10	Blade cleanliness			

Blade 3

Item	System / Component	Comments	Photo	Class
13.11	Blade structural condition			
13.12	Blade connection torque			
13.13	Blade surface			
13.14	Blade LPS			
13.15	Blade cleanliness			

14. Safety System

Item	System / Component	Comments	Photo	Class
14.01	Vibration switch			1
14.02	Overspeed gauge			1
14.03	Fire extinguishers			1
14.04	First aid box			1
14.05	Rescue evacuation rope			1

WIND TURBINE VISUAL INSPECTION	Wind Farm:	Hermanville Wind farm	DNV
	Wind Turbine:	T-9	

Inspection Data

Wind Turbine (WT):	T-9	*Inspector:*	Malcolm Moore
Wind Farm (WF):	Hermanville Wind farm	*Date:*	April 27, 2022
WF Location:	Souris, PEI, Canada	*From/To:*	8:40 AM 2:00 PM

Wind Turbine Data

WT Make:	Acciona	*Rated Power (kW):*	3,000
WT Model:	AW-3000/116	*Hub Height (m):*	92
Commissioned:	2014	*Rotor Diameter (m):*	116

Wind Turbine Components Identification

	Manufacturer	*Model/Type*	*Serial No.*
Gearbox:	*Winergy*	*PZAB 3535,0*	*NFC-W-100326*
Generator:	*Indar*	*TAR630XA6N60N*	*21516000009*
Blade A:	*Acciona*	*AW56.7*	*85*
Blade B:	*Acciona*	*AW56.7*	*89*
Blade C:	*Acciona*	*AW56.7*	*83*

Inspection Summary

Component Classification

	2	3	4	Total
1. Tower Foundation	2			2
2. Turbine Controls	1			1
3. Service Lift/Climb Assist				
4. Tower Sections	1			1
5. Yaw System	1	2		3
6. Hydraulic System				
7. Nacelle	4			4

	2	3	4	Total
8. Main Shaft	2			2
9. Gearbox	1			1
10. Generator	2			2
11. Top Box Controller	1			1
12. Hub Assembly & Pitch	3			3
13. Blades		1		1
14. Safety System				
Total	18	3	0	21

Visual Inspection Damage Classification

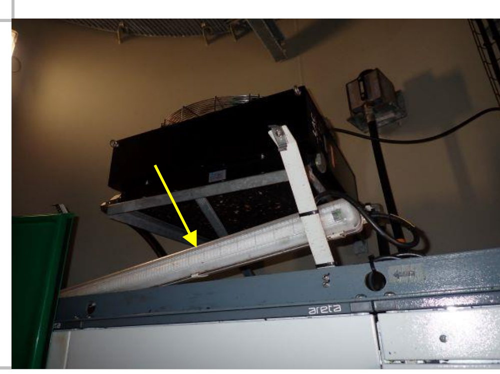
1	Normal condition	The component or equipment is typical for its age. May show some signs of wear although it is serviceable and no further action is needed.
2	Early signs of wear or damage.	Slightly damaged or worn equipment and/or missing part which presents no potential impact on turbine operation or safety. Despite no urgent corrective action is required, the damaged equipment or component should be repaired or replaced. Meanwhile the equipment or component should be monitored for progression of damage.
3	Advanced signs of wear or damage.	Equipment and/or missing part which presents a potential impact to the operation of the turbine and/or safety. Should be scheduled for repair or replacement in short term and no later than next scheduled service. Should be monitored until repairs or replacement takes place.
4	Failed or missing components.	The component has failed and/or missing and represents a critical impact to the operation of the turbine and/or a safety hazard. Component and wind turbine if deemed necessary must be taken out of service to prevent further damage. Immediate action to repair or replace is required before returning the component back to service.

1. Tower Foundation

Item	System / Component	Comments	Photo	Class

1.01	Foundation concrete condition	Moderate corrosion and paint chipping forming on base of foundation bolts		2
1.02	Foundation bolts condition			1
1.03	Tower external wall condition	Grease staining side of tower external wall		2
1.04	Tower verticality check			1
1.05	Padmount transformer condition			1
1.06	Tower stairs condition			1
1.07	Tower door condition			1
1.08	Tower door flange and seals			1
1.09	Tower door hinges and lock			1
1.10	Tower door screens and filters			1
1.11	Cleanliness of basement area			1

2. Turbine Controls

Item	System / Component	Comments	Photo	Class
2.01	Main control cabinet			1
2.02	Control panel			1
2.03	Cooling system			1
2.04	Converter			1
2.05	Breakers, switches, fuses			1
2.06	Cabling, splices			1
2.07	Grounding			1
2.08	Fans & filters			1
2.09	Light fixtures & LV	Light not functioning; bracket damaged		2

2.10	HV Switch gear cabinet			1
2.11	HV Switch gear control cable			1
2.12	HV Switch gear gauge check			1

3. Service Lift/Climb Assist

Item	System / Component	Comments	Photo	Class
3.01	Overall condition			1
3.02	Lift entry cage			1
3.03	Functionality of manual descent			1
3.04	Functionality of sensors			1

4. Tower Sections

Base Section

Item	System / Component	Comments	Photo	Class
4.01	Platform condition			1
4.02	Ladder condition			1
4.03	Safety cable condition			1
4.04	Hatch condition			1
4.05	Tower flange condition			1
4.06	Tower walls condition			1
4.07	Bolts condition, ping test			1
4.08	Grounding straps			1
4.09	Light fixtures and LV			1
4.10	Cabling, Splices			1

Mid Section(s)

Item	System / Component	Comments	Photo	Class
4.11	Platform condition			
4.12	Ladder condition			
4.13	Safety cable condition			
4.14	Hatch condition			
4.15	Tower flange condition			
4.16	Tower walls condition			
4.17	Bolts condition, ping test			
4.18	Grounding straps			
4.19	Light fixtures and LV			
4.20	Cabling, Splices			

Top Section

Item	System / Component	Comments	Photo	Class
4.21	Platform condition			
4.22	Ladder condition			
4.23	Safety cable condition			
4.24	Hatch condition			
4.25	Tower flange condition			
4.26	Tower walls condition			
4.27	Bolts condition, ping test			
4.28	Grounding straps			

Item	System / Component	Comments	Photo	Class
4.29	Light fixtures and LV	Open junction box to light fixture		2
4.30	Cabling, Splices			

5. Yaw System
Yaw Deck

Item	System / Component	Comments	Photo	Class
5.01	Platform condition	Loose platform hardware		2
5.02	Access ladder condition			1
5.03	Hatch condition			1
5.04	Safety cable top assembly			1
5.05	Grounding straps			1
5.06	Light fixtures and LV			1
5.07	Saddle cable condition			1
5.08	Torque check yaw ring			1
5.09	Yaw clamp condition			1
5.10	Yaw clamp manifold lines			1

Yaw Components

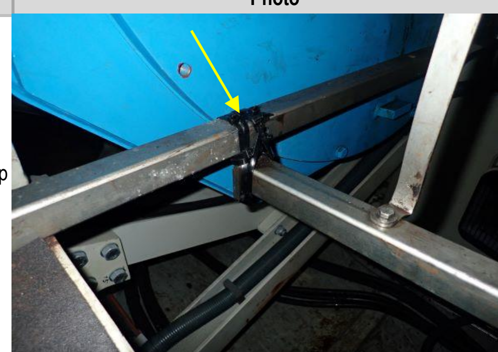
Item	System / Component	Comments	Photo	Class
5.11	Yaw motors condition	Yaw motor laying on nacelle platform		3
5.12	Yaw motors oil level, leakage			1

5.13	Yaw gear condition	Multiple yaw motors missing key components		3
5.14	Yaw gear lubrication			1
5.15	Yaw counter condition			1
5.16	Yaw position sensor condition			1

6. Hydraulic System

Item	System / Component	Comments	Photo	Class
6.01	Hydraulic pump condition			1
6.02	Accumulator condition			1
6.03	Hoses and couplings			1
6.04	Oil level, pressure			1
6.05	Radiator condition			1

7. Nacelle

Item	System / Component	Comments	Photo	Class
7.01	Main frame structural condition	High speed shaft cover structure being held by zip ties		2
7.02	Fiberglass condition, seams	Debris left on fiberglass seams		2
7.03	Insulation, soundproofing			1
7.04	Light fixtures and LV			1
7.05	MV Cabling, strain reliefs			1
7.06	Grounding straps			1

7.07	Nacelle hardware, condition	Missing hardware on main bearing support structure bracket		2
7.08	Hub adapter bolts, condition			1
7.09	Rotor lock condition			1
7.10	E-stop functionality			1
7.11	Hoist condition			1
7.12	Hatches, condition	Hatches/hardware left on nacelle platforms		2
7.13	Nacelle tie offs			1
7.14	Anemometer condition			1
7.15	Wind vane condition			1
7.16	Lightning receptor			1
7.17	Met mounting bracket			1

8. Main Shaft

Item	System / Component	Comments	Photo	Class
8.01	Main bearing condition			
8.02	Main bearing mounting hardware	Loose hardware on drive end of main bearing retainer plate		2

8.03	Main shaft condition	Loose hardware		2
8.04	Shrink disc condition			1
8.05	Shrink disc mounting hardware			1
8.06	Grease trap			1
8.07	Rotor plate deformation			1
8.08	Rotor plate shield			1

9. Gearbox

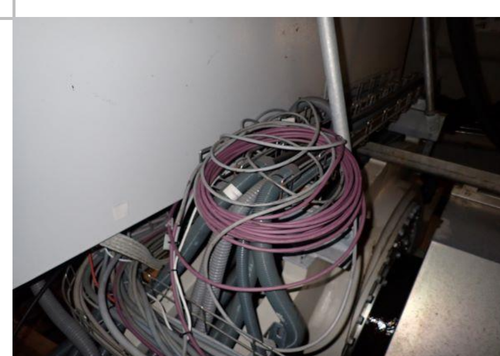
Item	System / Component	Comments	Photo	Class
9.01	Gearbox cover condition			
9.02	Gearbox mounting hardware	Broken hardware on gear box platform stairs		2
9.03	Gearbox access ports			1
9.04	Cooling system/circuit			1
9.05	Lubrication pump system			1
9.06	Breather filter condition			1
9.07	Gearbox oil level			1
9.08	Oil filtration system condition			1
9.09	Hoses and couplings			1
9.10	Pitch slip-ring, rotating union			1

10. Generator

Item	System / Component	Comments	Photo	Class
10.01	Generator cover condition			1
10.02	Generator feet torque markings			1
10.03	Cooling system/circuit			1

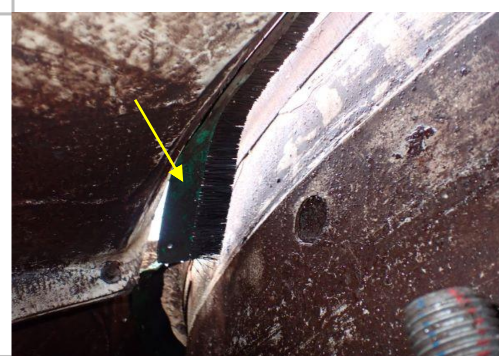
10.04	Lubricant system	Oversaturated oil filter		2
10.05	Generator bearings			1
10.06	Generator slip ring			1
10.07	MV cable condition, strain relief	melting of raceway and signs off excessive heat to cables		2
10.08	Brake disc condition			1
10.09	Brake clamps and calipers			1
10.10	Flexible coupler condition			1
10.11	Flexible coupler torque marks			1
10.12	Flexible coupler safety cover			1

11. Top Box Controller

Item	System / Component	Comments	Photo	Class
11.01	Control cabinet condition			1
11.02	Air extraction fan filters			1
11.03	Wire Connections and Cabling	Cluttered cable tray		2
11.04	Grounding			1

12. Hub Assembly & Pitch

Item	System / Component	Comments	Photo	Class

12.01	Mounting hardware condition	Loose hardware near hub entry		2
12.02	Access hatch condition			1
12.03	Blade bearing seals	Moderate grease leak forming in hub structure		2
12.04	Fiberglass nose cone condition			1
12.05	Cleanliness hub internal	Missing blade protection near hub entry		2
12.06	Blade internal protective covers			1
12.07	Rotating union condition			1
12.08	Control box condition			1
12.09	Light fixture and LV			1
12.10	Hydraulic system leaks			1
12.11	Pitch accumulator condition			1
12.12	Pitch ram cylinder condition			1
12.13	Pitch cylinder bearing condition			1
12.14	Pitch cylinder connection points			1

13. Blades
Blade 1

Item	System / Component	Comments	Photo	Class
13.01	Blade structural condition			1
13.02	Blade connection torque			1
13.03	Blade surface			1
13.04	Blade LPS			1
13.05	Blade cleanliness			1

Blade 2

Item	System / Component	Comments	Photo	Class
13.06	Blade structural condition			1
13.07	Blade connection torque			1
13.08	Blade surface			1
13.09	Blade LPS			1
13.10	Blade cleanliness			1

Blade 3

Item	System / Component	Comments	Photo	Class
13.11	Blade structural condition			1
13.12	Blade connection torque	3 blade studs missing/damaged		3
13.13	Blade surface			1
13.14	Blade LPS			1
13.15	Blade cleanliness			1

14. Safety System

Item	System / Component	Comments	Photo	Class
14.01	Vibration switch			1
14.02	Overspeed gauge			1
14.03	Fire extinguishers			1
14.04	First aid box			1
14.05	Rescue evacuation rope			1

APPENDIX C – TECHNICAL REVIEW OF THE NORDEX/ACCIONA WINDPOWER AW3000 WIND TURBINE PLATFORM

Technical Review of the Nordex/Acciona Windpower AW3000 Wind Turbine Platform

Document No.: 702806-TR-AC-30
Issue: AF; **Status**: Draft
Date: 7 April 2021

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This report presents the results of an independent technical review of the Acciona AW3000 Platform carried out by DNV.

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B - W	2014-2018	See previous versions			
X	09 April 2018	Various updates, including hub slippage and blade issues	P. Brodeur	M. Malkin, T. McCoy	P. Brodeur
Y	27 July 2018	Various updates (focused on blades)	P. Brodeur	M. Malkin, A. Yupa	P. Brodeur
Z	21 December 2018	Various updates based on Acciona feedback, including detailed meetings on blade issues, and addition of AW140	P. Brodeur	M. Malkin	P. Brodeur
AA	20 May 2019	Update blade language	M Malkin	D. Griffin	P. Brodeur
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AD	03 July 2020	Various updates (focused on known issues)	B. Cicierski	M. Malkin	P. Brodeur
AE	16 July 2020	Minor update to Table 3-1 for AW140/3000 certification status	B. Cicierski	M. Reha	NA
AF	7 April 2021	Various updates (focused on known issues)	B. Cicierski, K. Smith	M. Malkin, D. Griffin	P. Brodeur

Table of contents

List of tables

List of figures

List of abbreviations

Abbreviation	Meaning
AEP	Annual energy production
AWP	Acciona Windpower
CENER	Centro Nacional de Energías Renovables (Spain’s national renewable energy center)
CF	Contributing factor
CFD	Computational fluid dynamics
CMS	Condition monitoring system
COE	Cost of energy
CTQ	Critical to quality
DEWI	Deutsches Windenergie Institut (German wind energy institute)
DFIG	Doubly fed induction generator
DIBt	Deutsches Institut für Bautechnik
EHN	Corporación Energía Hidroélectrica de Navarra
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
FEM	Finite element modelling
GL	Germanischer Lloyd SE
GLPS	Global Lightning Protection Systems A/S
DNV	DNV Energy USA Inc.
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LPS	Lightning protection system
LPL	Lightning protection level
O&M	Operation & maintenance
OEM	Original equipment manufacturer
OHSAS	Occupational Health and Safety Assessment Series
PCC	Point of common coupling
QA/QC	Quality assessment and quality control
RC	Root cause
RCA	Root cause analysis
SCADA	Supervisory control and data acquisition
SoC	Statement of Compliance
SQE	Supplier quality engineering
TBD	To be determined
TMT	Times New Material Technology Co.

UT	Ultrasonic testing
WTG	Wind turbine generator

EXECUTIVE SUMMARY

In 2016, Nordex and Acciona Windpower completed a merger; the transaction entailed the acquisition by Nordex of Acciona Windpower from its parent company, Acciona S.A, which is now the major shareholder in Nordex with a total stake of approximately 36%. The merged company is currently being referred to as the Nordex Group (also referred in this report as "the wind turbine manufacturer", or "AWP"). Following the merger, the company now has approximately 8,400 employees and a combined installation track record of over 31.8 GW.

Acciona S.A. became involved in wind power first as a project developer and turbine owner-operator. After owning multiple wind turbines from other original equipment manufacturers (OEM), the company decided to start its own wind turbine business, as Acciona Windpower, in 1999. AWP's first wind turbine was installed in 2000, and significant commercial installations began in 2004, mostly for AWP-owned wind projects. In 2006, AWP started to sell a significant portion of its wind turbines to third parties. AWP assembles nacelles and hubs and can manufacture its own blades (through subsidiary Acciona Blades). AWP subcontracts all other component manufacturing and also uses third parties for blade and concrete tower production. DNV finds that the supply chain for AWP turbines is managed in accordance with industry standard practice.

The design and development of the AW3000 turbine platform dates back to 2006, although commercial installations did not start until 2012 as the company heavily invested in prototyping (14 wind turbine generators (WTG)) and industrialization to prepare for commercial deployment. The design of the AW3000 is based on AWP's experience with the AW1500 turbine series as well as experience gained by Acciona Energy in the operation of multiple projects with other types of wind turbines. The AW3000 turbines can be considered an up-scaled version of the AW1500 that uses the same overall turbine design concept, although it represents twice the nameplate rating and is available with a range of significantly larger rotor options.

The AW3000 turbine platform was initially launched with the AW100 and has since increased in rotor size, now having rotors up to 140 m, with various power ratings up to 3,465 kW. While the overall design concept has stayed the same for all turbine models, nacelle and hub reinforcements have been done as necessary to account for higher loads. The initial AW100 and AW109 models have now been discontinued, and the AW116, while still commercially available, has mostly phased out. Current rotor sizes currently include 125 m, 132 m and 140 m, and a 148 m rotor is currently in the late stages of design phase.

The turbines are offered with multiple hub heights and either steel or concrete towers. The turbines are variable-speed, with collective blade pitch control (one signal is sent to all three independent pitch actuators, which provide for fail-safe operation). The overall turbine concept is similar to that which has been adopted for many large wind turbines currently in operation, with the exception of the 12 kV generator, which AWP has already used successfully on the AW1500 platform.

The first prototype of the AW3000, with a 100 m rotor and a 100 m concrete tower, was installed in October 2008 in Spain, two years after the design efforts started on the AW3000. AWP has since installed and tested various configurations for type certification, with the most recently installed prototype being the AW140/3000. Commercial installations of the AW3000 platform began in late 2012 and, as of the end of 14 January 2021, global installations of the platform comprise over 2,491 turbines (7,714 MW installed). AWP also reports a firm order backlog of approximately 2,442 MWs for the AW3000 platform.

DNV has performed a fleet availability audit for the AW125/3000 in July-August 2017. The fleet considered included more than 100 turbine-years of operation and resulted in a DNV calculated wind-in-limits turbine availability of 96.9%, thus exceeding DNV's requirement of 95%. While the availability audit shows that the turbine meets DNV's criterion of above 95% availability, in parallel to the audit DNV has been made aware of issues occurring in the AW3000 fleet (in particular blade delamination and web separation, and blade stud failures, as described in this report). As of May 2020, AWP has completed a full-scale blade test on an AW61.2 blade to assess the effects of delamination and cavities (and associated cracks) on the full structural capability of the blade. The blade successfully completed testing, showing that the tested blade is capable of withstanding 20-year design loads, with delamination and proposed shear clip retrofit to contain web separation. AWP's blade stud failure RCA is well advanced and AWP has reported progressing corrective actions. These issues first occurred in June-July 2017 and as such, are subsequent to the data sample period reviewed by DNV and therefore not captured in the availability figure presented above.

AWP has well established engineering, manufacturing, and field service capabilities. With installations of 391 wind turbines for the AW116, 1,299 wind turbines for the AW125, and 221 wind turbines for the AW132 as of the end of April 2020, and based on the availability data reviewed and AWP's demonstrated experience with operations of turbines in North America, DNV considers the AW116/3000, AW125/3000, AW125/3150, AW132/3000, AW132/3300, and AW132/3465 turbines to be qualified in North America.

DNV recommends assuming a one-year ramp-up in availability after commissioning, with nominal turbine availability of 96.0% being achieved for the AW125 and AW132 turbines (and a nominal availability of 95.5% for the AW140). This assumes typical construction and initial operational teething issues will have been overcome, with good operations and maintenance practices. The nominal availability represents the expected average availability in project years two to ten, with declining levels expected in subsequent years.

1 INTRODUCTION AND BACKGROUND

1.1 Objectives of this report

DNV has performed a technical review of the AW3000 wind turbine, with the objective of providing an independent assessment of the turbine and its associated strengths and risks. This review was based on information obtained from the following sources:

- Public domain information;
- Information in the DNV archives;
- Information provided by the wind turbine manufacturer; and
- Information obtained by DNV in the course of other work that is not subject to Confidentiality Agreements.

It should also be noted that turbine technical specifications were recorded from product information, which was either made available in the public domain or directly supplied by the turbine manufacturer. DNV cannot be held responsible for the accuracy of information supplied by turbine manufacturers; however, DNV has applied a test of reasonableness to the information and if there are any obvious errors, these have been indicated in the text.

1.2 Wind industry background

Table 1-1 shows the installed capacities of the most widely installed wind turbine manufacturers in 2019. The Nordex Group ranked sixth largest supplier in terms of cumulative installed capacity and seventh largest supplier in terms of worldwide deliveries in 2019.

Table 1-1 Market share of largest turbine manufacturers (based on 2019 installations)

Manufacturer	Accumulated worldwide delivered capacity as of end of year [MW]					Worldwide deliveries [MW] 2019
	2015	**2016**	**2017**	**2018**	**2019**	
Vestas [1]	71,166	79,946	87,828	97,512	109,175	11,372
SGRE [2]	67,089	74,806	83,665	89,836	99,502	9,665
GE [3]	51,720	59,078	63,431	68,987	77,531	8,746
Goldwind	30,936	37,375	42,765	49,819	57,890	8,075
Enercon	38,313	41,647	45,073	47,918	49,483	1,576
Nordex Group [4]	**17,749**	**20,772**	**23,726**	**26,238**	**28,784**	**2,496**
Envision	7,020	8,867	12,129	16,714	22,875	6,161
United Power	14,449	16,351	18,109	19,119	19,839	720
Mingyang	10,084	11,900	13,387	15,387	19,822	4,435
Suzlon	15,497	16,641	17,998	18,895	19,299	404
Senvion	13,651	15,123	17,034	17,736	18,895	1,131
Sinovel	16,515	16,803	16,803	16,803	16,803	0
DEC	10,589	11,639	12,334	12,987	14,307	1,320
SEwind	7,233	8,961	10,076	11,217	12,555	1,338
XEMC	6,991	8,195	9,000	9,600	10,250	650
Remaining others	55,067	62,302	69,020	73,195	79,675	6,557
Total	**434,069**	**490,403**	**542,376**	**591,962**	**656,684**	**64,646**

Source: Historical global wind turbine OEM market share database **Error! Reference source not found.**. The data and i nformation provided by Wood Mackenzie should not be interpreted as advice and you should not rely on it for any purpose. You may not copy or use this data and information except as expressly permitted by Wood Mackenzie in writing.

1. Vestas figures do not include MHI Vestas Offshore Wind.
2. SGRE cumulative figures include historical Gamesa and Siemens market share.
3. GE cumulative figures include historical Alstom cumulative capacity.
4. Nordex Group cumulative figures include historical Acciona Windpower cumulative capacity.

2 COMPANY PROFILE

2.1 Company history

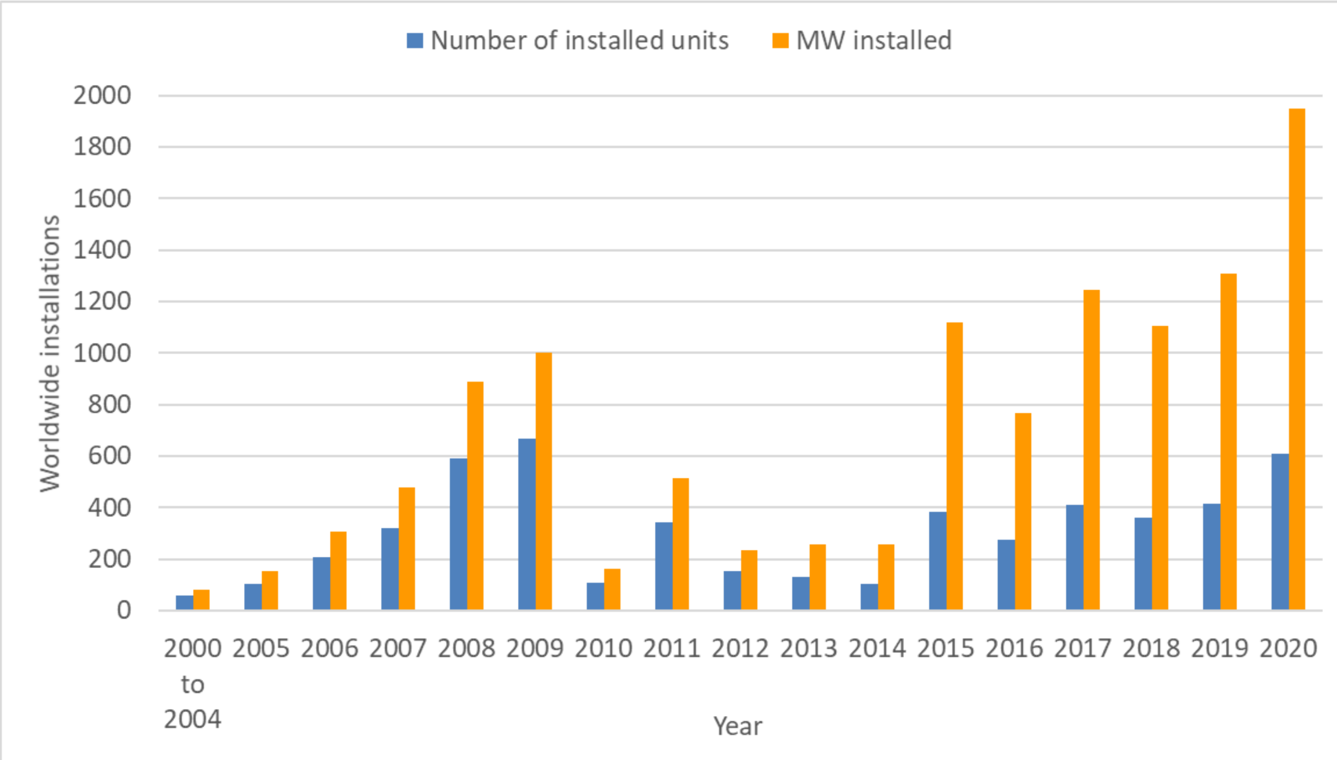
In April 2016, Nordex and Acciona Windpower completed a merger; the transaction entailed the acquisition by Nordex of Acciona Windpower from its parent company, Acciona S.A, which is now the major shareholder in Nordex with a total stake of approximately 36%. The merged company is now officially called Nordex Group (also referred herein as "the wind turbine manufacturer" or "AWP"). Following the merger, the company now has a combined installation track record of over 28.8 GW, and as of March 2021, AWP had more than 8,400 employees globally. For the purpose of this report, only the AW3000 product line is reviewed.

Two referenced companies are mentioned in the course of this turbine review:

Acciona Energy: Acciona Energy (or Acciona Energía) is a leader in the Spanish renewable energy market, comprising approximately 105 companies working in the development, construction, and operation of renewable energy facilities (including hydroelectric, biomass, solar, and wind farm projects). Acciona Energy is one of the largest developers and operators of wind farms in the world; it also provides support and services to other companies in the renewable energy field. As of the end of 2014, Acciona Energy owned and operated over 9,000 MW of wind power capacity [2].

EHN: a hydroelectric company, originally Corporación Energía Hidroélectrica de Navarra (EHN), began developing wind power projects in 1994. In parallel with the outsourcing of turbines, EHN decided to develop a turbine design in-house. The design was based on EHN's extensive experience in developing and operating wind farms. The turbine was developed by Ingetur, a wholly-owned subsidiary company of EHN. In 2005, Acciona S.A. acquired EHN and Ingetur and became Acciona Windpower.

Figure 2-1 presents the annual worldwide installations of AWP turbines, from 2000 through to the end of 2020. In 2008, AWP was eighth in the world for installed capacity, with a market share of 4.6%. The subsequent slowdown in the Spanish wind turbine market had a negative impact on AWP's installation figures, and in addition, the wind turbine market as a whole became more competitive in AWP's primary markets. During that slower period of commercial activity, AWP focused on a multi-year effort of development, prototyping, and measurement for the AW3000 platform. Significant commercial deployment of the AW3000 turbines began in 2011.



Source: Nordex Group

Figure 2-1 AWP product line installation history worldwide

2.2 Turbine product line

AWP's wind turbine offerings as of March 2021 are shown in Table 2-1. This report is focused on the AW3000 platform. AWP also advised that an AW148 wind turbine is currently in the late stage of design development; this turbine model will not be included in the current turbine review.

Table 2-1 AWP product line

Turbine platform	Power [MW]	Rotor diameter [m]	IEC Class	First installation
AW1500	1.5	70	IA	2004
		77	IIA	2004
		82	IIA	2008
AW3000	3.0	116	IIA	2012
		125	IIB	2015
		132	IIB	2018
		140	S	2018 [1]
	3.15	125	IIB	2017
	3.3	132	IIB	2018
	3.465	132	S	2019

[1] Installation of 50 Hz prototype only, no commercial installations as of 31 December 2019

2.3 AWP manufacturing capabilities

AWP S.A.'s involvement in wind power has originally been as project developer and turbine owner-operator. The AWP venture was, until 2006, a relatively minor part of Acciona S.A., supplying turbines primarily to AWP Energy projects. This changed in 2006-2007 when AWP started selling WTGs to third-party customers and expanding its role in the global marketplace. In recent years, AWP has continued to sell a significant portion (~85%) of its wind turbines to third parties, which is currently the primary business model of the company.

Over the past years, DNV visited AWP on multiple occasions, including meetings and discussions at AWP's headquarters and visits to AWP's nacelle and blade facilities, all located near Pamplona, Spain. DNV also visited some of AWP's blade suppliers, including TPI (China) and Indutch (India). DNV notes that during these visits and meetings, AWP was responsive to DNV's questions, and provided the required documentation, showing transparency during the whole process. DNV considers AWP's openness to be a positive element of this review.

DNV visited the Barásoain assembly plant at multiple occasions in past years. The facility production capacity is 7 nacelles (AW3000) per week if crews are working 7 days per week on 3 shifts. The facility currently employs approximately 400 employees [4]. AWP controls the quality of incoming components in the supply chain first by supplier qualification and second by reviewing the quality documentation of every received component, as well as performing a visual inspection. This is standard practice and is considered to be typical for "just in time" supply chain management.

After a nacelle has been fully assembled, it is subjected to a final functional test in the factory. The functional test checks all of the mechanical and electrical system functions and simulates operation of the turbine. The nacelle is tested at the generator's nominal rpm for approximately one hour, with the generator energized in inverse mode with no load on the drivetrain. Vibrations are measured, and the cooling system is tested. Tests include a check for leakage, short circuit, and signal failures. DNV considers this facility to be equipped for high quality assembly of turbine nacelles and hubs. AWP performs a final test of all nacelles leaving the plant, in accordance with industry best practice.

AWP blade production facilities include:

- AWP blade factory in Lumbier, Spain. DNV visited the manufacturing facilities and overall finding was that manufacturing practices are on par with industry standards. Quality checks of produced blades and non-destructive inspections are performed in line to industry practices. Based on the observations made by DNV to this facility, DNV considers the quality of the blades produced by AWP Blades to be consistent with industry standard.
- TPI factory in Dafeng, China. DNV visited the production facility and considers TPI a top-tier third-party blade manufacturer with significant in-house knowledge of blade production. AWP have two full-time dedicated employees stationed at the TPI Dafeng facility. Overall the facility, equipment, quality assurance/quality control system, and blade manufacturing processes at TPI Dafeng were found to be consistent with industry standards.
- Aeris factory in Brazil. Aeris produces blades for the Brazilian market and DNV has not performed any factory visit to this facility.
- Indutch factory in Chennai, India. Indutch started production in January 2018. AWP has a strong presence in this facility. DNV observation is that since this is a new factory, there are manufacturing

steps and processes that can be improved to reach a smoother production line. Overall the facilities, equipment, quality assurance/quality control system, and blade manufacturing processes at this facility were found to be consistent with industry standards.

- Nordex blade factory in Matamoros, Mexico. DNV inspected the manufacturing facility in February 2020 and found that manufacturing practices are generally on par with industry standards for a facility in early stages of production. The factory started producing blades in June 2019, and at the time of the visit, approximately eight NR74 blades (for the N149 turbine), 40 AW64.7 blades (for the AW132/3000 turbine) and 42 AW68.7 blades (for the AW140/3000 turbine) had been produced, with a portion of these still unfinished (blades fully assembled, but with some repairs or painting still to be completed). As such, as of February 2020, the facility was still in early stages with relatively low production rates, but DNV expects production rates to continue to increase as further experience is gained. DNV notes that certain production processes have room for improvement, which AWP is actively working on, both by bringing external blade specialists to help out at the facility and train Nordex employees, and by sending Matamoros workers to other well-established Nordex blade facilities (in Germany and Spain) for training purposes. In DNV's opinion these actions are positive and demonstrate Nordex's interest in building a capable workforce at the factory.
  Based on observations made by DNV in this facility, DNV found the facility to be suitable for blade production, and Nordex personnel were welcoming and willing to share information. Overall, DNV had a generally positive impression of the factory capability.
  As of the DNV visit, this facility was not certified to ISO9000, however Nordex indicated that the system is planned to be certified to ISO9000 by the end of 2020. The facility had two blade molds for the N149 turbine and two blade molds that could be used for the AW132/3000 or AW140/3000 turbine.

The AWP blades manufactured by TPI, Aeris and Indutch are AWP's "built-to-print" designs. From the DNV visits to the various facilities, deviations in some production processes and parameters were noted between Acciona's own manufacturing plant and build-to-print facilities. DNV suggests AWP to implement a consistent set of production parameters to ensure consistency in blade production processes across factories producing AWP blades.

AWP has advised that they have added a new supplier to their blade supply chain: Times New Material Technology Co. (TMT) will be supplying Acciona designed "built-to-print" blades, starting production in December 2018. TMT is based out of China.

2.3.1 Research and development

The design of both the AW1500 and AW3000 Series turbines were overseen by AWP's in-house engineering team. All major engineering disciplines (including electronics, control, mechanical and electrical engineering) were involved with the in-house turbine design. AWP also has relationships with various external companies that can assist with certain design aspects when needed. This philosophy has also been adopted by other turbine manufacturers and allows a greater degree of flexibility compared with maintaining all engineering design in-house.

The engineering team has gained considerable experience in wind turbine operation in the course of its development over a period of approximately 20 years. Most of the core team from the original conceptual design is still with the company, leading respective functional areas within the Engineering department. The engineering team also includes a significant number of staff with experience from other wind turbine manufacturers; significant experience was also gained by performing operations and maintenance (O&M) on other OEM's wind turbines.

In evaluating and selecting turbine technologies, AWP prioritizes reliability, cost-of-energy, and time-to-market. As such, the technologies selected for the AW3000 were consistent with those that had been proven in the AW1500 platform, and mostly within the range of current mainstream technologies. The use of a medium-voltage generator is one innovation of note. This architecture typically eliminates the need for step-up transformers as part of the site electrical collection system. This design feature was introduced based on the input of wind farm developers and operators. Another significant innovation is concrete towers, with hub height of up to 137 m.

2.3.2 Quality control

AWP holds an ISO 9001:2015 quality system certificate for the design, manufacture, assembly, and commissioning and servicing of wind turbines at its Spanish, Brazilian and India facilities; the certificate was issued by Bureau Veritas and is valid until 13 August 2021. These facilities also have a system of environmental management that complies with the requirements of ISO 14001:2015 and a health and safety accreditation that complies with OHSAS 18001:2007, both also certified by Bureau Veritas, with certificates valid until August 2021 and March 2021, respectively. In general, DNV finds that the quality management system and its certification are in line with the industry standard. AWP's Spanish QA department has a team of 15 staff, including QA inspectors for assembly processes undertaken in the workshop.

The West Branch, Iowa facility of AWP North America is covered under separate certificates, although it includes the same three certifications all issued by Bureau Veritas: ISO 9001:2015 and ISO 14001:2015 and OHSAS 18001:2007. The OHSAS 18001:2007 certification is valid until 22 October 2019, while Acciona advised that the facility transitioned to the 2015 ISO certificate in June 2018; the facility has gone through successful audits and both ISO 9001:2015 and ISO 14001:2015 certificates are expected very soon.

2.3.3 Supply chain strategy

AWP's manufacturing consists mainly of assembling nacelles and hubs, manufacturing concrete towers, and producing a portion of the rotor blade production for the AW1500 and AW3000 platforms. AWP produces blades for the AW116/3000, AW125/3000 and AW132/3000 turbines through Acciona Blades located in Lumbier, Spain. AWP assembles turbine nacelles and hubs at the following facilities: Barásoain (Spain); la Vall d'Uixó (Spain); Bahia (Brazil) and Chennai (India). AWP reports a total production capacity of 1,100 MW wind turbines per year globally for its 3 MW platform. In late 2007, AWP opened a wind turbine plant in West Branch, Iowa, for the North American market, which has a production capacity of 800 MW/year. However, as of Q2 2018, it is understood that this plant is not in production and that all capacity production for the North American market is coming from the facilities in Spain.

AWP subcontracts all other manufacturing, including the manufacture of AWP's own blade design using the "build-to-print" concept for the AW125, AW132 and AW140 blades, working in partnership with Aeris in Brazil, TPI in China and Indutch in India. As of Q2 2018, there were 10 molds available globally for the AW3000 platform.

AWP's manufacturing concept, working with multiple subcontractors, is similar to that employed by other turbine manufacturers, both large and small. Table 2-2 presents AWP's suppliers for the AW3000 major components – specific suppliers may vary for different turbines models, this should be verified on the respective type certificates.

Table 2-2 Major component supply chain

Component	Possible suppliers
Blades	In-house design: AWP manufacturing (Spain and Mexico) or built-to-print by TPI (China), Aeris (Brazil), Indutch (India), TMT (China)
Gearbox	Moventas, Winergy
Generator	INDAR, ABB, ELIN, Siemens
Main bearing	SKF, NTN, KOYO, FAG
Converter	Ingeteam, ABB
Controller	Ingeteam, Elektra, BBKAT

With an exception for Indutch, which is a newer blade manufacturer, the current sub-suppliers of main components to AWP are all well-established suppliers to the wind industry, with most of the same suppliers used for the AW3000 as have been used for the AW1500. These facts add comfort to DNV's perspective on both the design and manufacturing quality of these source-controlled turbine components.

Like most turbine manufacturers, AWP is routinely looking for new suppliers. During various meetings with DNV in the past, AWP presented its procedure for the introduction of new suppliers. This process includes pre-production, or "first article" inspection, involving the AWP development department. Components used in the turbine are divided into three categories and AWP allows only suppliers with ISO 9001 certification to be used for the two most important categories.

DNV finds that the supply chain for AWP turbines is managed in accordance with industry standard practice.

2.3.4 Service and maintenance capabilities

Originally, AWP had no internal service department, and all servicing of AWP turbines on commercial projects was either performed by Acciona Energy (which owns the majority of the AWP turbines) or subcontracted to third parties under warranty. Since then, AWP has established its own service department, independent of Acciona Energy. DNV expects that AWP has used the experience from Acciona Energy to establish its service department and ensure that the servicing of its turbines is performed in accordance with industry standards. AWP's O&M strategy may vary from region to region. When servicing larger projects in regions with an established presence, AWP typically places a site manager on each site, while service technicians may be subcontracted. In less mature markets, AWP will generally have more AWP technicians performing O&M, in order to ensure that AWP's quality requirements are met.

DNV has inspected AWP turbines in Europe and the United States, in addition to other turbine brands serviced by Acciona Energy in Spain. DNV finds that AWP is capable of performing wind turbine servicing in line with established industry standards.

2.3.4.1 Remote monitoring

Remote monitoring is performed by Acciona Energy under a subcontract agreement, which has established three turbine monitoring and control centers in Pamplona, Spain, Mexico City, Mexico, and Chicago, U.S. with redundant capabilities to control any wind farm from any control center. Each control center has multiple workstations, including extra workstations that are not in use but are fully functional and could be used by calling-in additional personnel, in case another control center is needed to be taken offline (in case of a natural catastrophe, for example). Altogether, the three control centers monitor nearly 10 GW of assets under operation, including wind (multiple turbine OEMs), hydro and photovoltaic facilities. About 8.5 GW are owned by Acciona Energy and 1.5 GW by others. DNV visited the Pamplona control center on 12 February 2015.

Supervisory control and data acquisition system (SCADA) data from every turbine are sent to these centers and monitored 24 hours a day. Staff at the centers can control the turbines remotely, including fault resets; other responsibilities of the centers include coordinating maintenance activity and recordkeeping.

DNV considers AWP's capabilities for remote monitoring to represent good industry practice, and considers AWP's redundant capabilities to remotely operate its projects a good risk mitigation practice.

3 TURBINE TECHNOLOGY DESCRIPTION

3.1 Overview

The AW3000 turbine platform includes multiple turbine versions, the most commonly installed to date being the AW116/3000, the AW125/3000, and the AW132/3000, with multiple hub heights available with either steel or concrete towers. The principal differences between the versions are the rotor diameter and other (resultant) modifications, such as rotational speed. The design wind class is adjusted to suit the individual turbine, which compensates for the larger rotor. Turbine loading behind the rotor is therefore similar for all three variations.

Additionally, AWP has introduced uprated variants to the platform including the AW125/3150, AW132/3300 and AW132/3465. The AW125/3150 version is nearly identical to the AW125/3000 turbine although it includes minor changes to the generator (higher rating) and gearbox (increased ratio on high speed stage) and operates at a lower rotational speed but similar maximum sound power levels.

The AW132/3300 and AW132/3465 are nearly identical to the AW132/3000 although they include changes to the generator (higher rating) and cooling system.

In addition, AWP has developed an AW140/3000 for lower wind sites. This variant has three changes when compared to the AW132/3000: the blade consists of a longer (cylindrical) root section but otherwise has identical blade construction as the AW132. There is also an increase to the ratio on the high-speed stage of the gearbox. Finally, the software and controls have been adapted for the longer blades.

AW3000 wind turbines are variable-speed, with independent blade pitch control (blades pitched collectively in operation, also called symmetric pitch). The conceptual design of the AW3000 follows the earlier design work of the AW1500 series. The overall turbine concept is also similar to that which has been adopted for most large wind turbines currently in operation, with the exception of the medium-voltage generator, as further described below.

The design and development of the AW3000 turbine platform dates back to 2006, although commercial installations did not start until 2012 as the company invested in prototyping (14 WTGs) and industrialization to prepare for commercial deployment. The first prototype of the AW100/3000, with a 100 m concrete tower, was installed in October 2008 in Spain. This prototype was modified in early 2010 by changing the rotor to make it an AW109/3000. The first AW116/3000 was installed on a 120-m concrete tower in 2012 at a location provided by the National Renewable Energy Center (CENER) in Pamplona, Spain. Commercial installations of the AW3000 platform began in late 2012. The first AW125/3000 prototype was also installed in Spain in 2014 near AWP's headquarters.

Figure 3-1 presents a cutaway view of the AW3000 nacelle. The main characteristics of four turbines in the AW3000 series are summarized in Table 3-1. The certifications noted in Table 3-1 are only representative examples. Not all combinations of rotor diameter, hub height and their associated natural frequencies are certified, so certification status should be reviewed on a project basis depending on which turbine configuration is to be supplied.

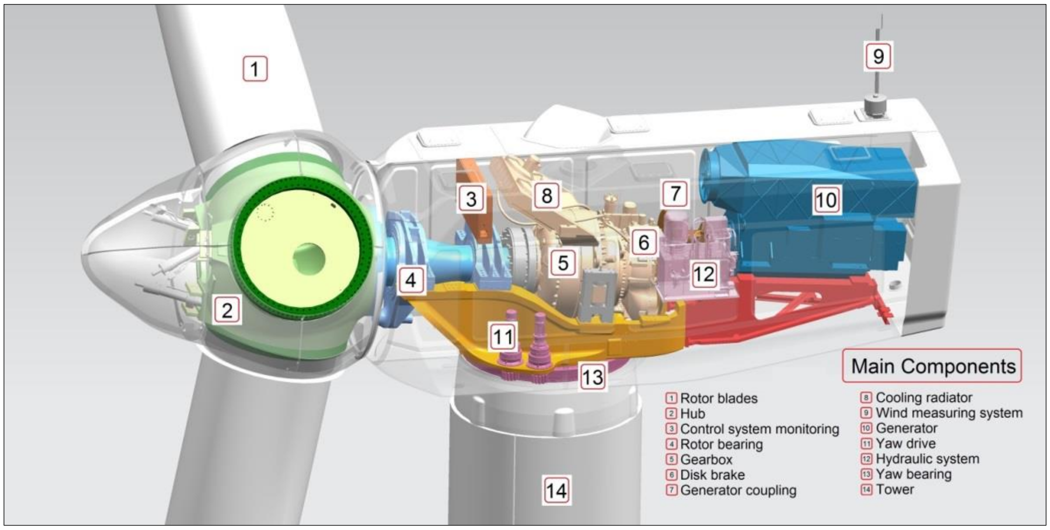


Figure 3-1 Cutaway of the AW3000

Table 3-1 Summary description of the AW3000 turbines

Item	AW116/3000	AW125/3000 AW125/3150	AW132/3000 AW132/3300 AW132/3465	AW140/3000
Hub height(s) [1] [m]	92 (steel), 100 and 120 (concrete)	87.5 (steel), 80, 100, 120, and 137.5 (concrete)	84 and 112.5 (steel), 120 (concrete)	82 and 105 (steel), 120 (concrete)
Rotor diameter [m]	116	125	132	140
Rated power [kW]	3,000	3,000 3,150	3,000 3,300 3,465	3,000
IEC design wind class	IIA	IIB	IIB IIB S	S
IEC classification edition	Ed. 2 (1999)			
Certification status	Type certificate	Type certificate	Type certificate	Type certificate [2]

Item	AW116/3000	AW125/3000 AW125/3150	AW132/3000 AW132/3300 AW132/3465	AW140/3000
Cut-in & Cut-out [m/s]	3 - 25			3 - 20
Rotor speed range [rpm]	9.2 – 15.6	9.2 – 15.6 7.3 – 14.7	7 – 14	6.6 – 13.2
Nominal tip speed [m/s]	80.3	86.5	80.4 85.5 87.2	85.5
Gearbox Ratio	1:83 (50 Hz)/1:100 (60 Hz)	1:83 (50 Hz)/1:100 (60 Hz)	1:97 (50 Hz) / 1:117 (60 Hz)	1:103 (50 Hz) / 1:124 (60 Hz)
Generator/Converter type	DFIG/Partial Conversion			
Power regulation	Pitch to feather			
Blade pitching type	Hydraulic, independent pitch system operating to a common setpoint		Hydraulic, independent pitch system operating to a common setpoint with slightly larger pitch bearings/plates	Hydraulic, independent pitch system operating to a common setpoint
Blade type, structure, material	Fiberglass reinforced epoxy structural shell with full-length spar. Same blade design up to 48 m			
Shaft support	2 main bearings			
Main bearing configuration & type	Two spherical roller bearings			
No. of yaw drives & yaw brake type	6, hydraulic calipers			
Tower	4 sections cylindrical steel (92 m), 5-section concrete (100 m), 6-section concrete (120 m)	3 or 4-section cylindrical steel (87.5 m) 4-section concrete (80 m), 5-section concrete (100 m), 6-section concrete (120 m), 7-section concrete (137.5 m)	4-section cylindrical steel (84 m), 5-section cylindrical steel (112.5 m), 6-section concrete (120 m)	3 or 4-section cylindrical steel (82 m) 6-section concrete (120 m)
Transformer type & location	Padmount (outside) or inside bottom of tower [3]			
Condition monitoring system (standard & optional)	Standard: • Temperature: oil, air, bearing, windings • Oil: filter pressure standard Optional vibration monitoring available in gearbox and on other bearings			
Service hoist capacity	150 kg			
Maintainability comments	Gearbox can be removed without rotor removal. Auto-lube optional for all bearings. Lift is standard. Nacelle cover recently redesigned for improved maintainability. Hub access without exiting the nacelle.			

Item	AW116/3000	AW125/3000 AW125/3150	AW132/3000 AW132/3300 AW132/3465	AW140/3000

Source: Turbine design certificates and AWP documentation [5]

1. Some combinations of rotor diameter, hub height and power rating may not be available for all turbines.
2. As of July 2020, Type certificate for 120 m hub height only; the 82 m hub height variant has a Design certificate and is expected to obtain a Type certificate in the future.
3. As required; the AW3000 generator runs at 12 kV, such that a step-up down tower transformer may not be needed at all sites.

Table 3-2 summarizes the similarities of the key technology design elements versus the industry norm.

Table 3-2 Comparison of key design elements with industry norm

Component/ Process	Design established within industry norm	Comments
Blade design and manufacturing	Yes	General design and manufacturing processes are common to several other large turbine manufacturers.
Pitch system	Yes	Hydraulic, one of two industry standard types
Drivetrain	Yes, see comments	The gearbox input stage is planetary, but has four planets; this differs from the more commonly used arrangement of three planet gears previously used in smaller wind turbines, although it is a common solution for 3+ MW wind turbines.
Power conditioning	Yes, see comments	The use of a medium-voltage generator is unique to AWP; AWP has successfully used a 12 kV generator for the proven AW1500 platform.
Yaw system	Yes	6 electric, geared yaw drives plus hydraulic brakes
Tower	Steel: yes Concrete: innovative and relatively new, see comments	While becoming more popular in the industry particularly for higher towers, the use of reinforced concrete is still uncommon. However, AWP has installed over 500 concrete towers for the AW3000 platform with varying rotor size and height (along with 85 for the AW1500 platform). Other OEMs have also successfully used concrete or hybrid concrete/steel towers.

3.2 Rotor components

3.2.1 Blades

The AW56.7 blade for the AW116/3000 turbine is made of fiberglass reinforced epoxy. The blade has fiberglass spar caps, two main shear webs, PVC and balsa wood cores for the shell sandwich structure, and a T-bolt style root connection. DNV considers the blade to have a typical design configuration that has been used by multiple blade manufacturers; AWP has used a similar design for the AW1500 blade of their own design. The AW56.7 has an approximate weight of 14.8 tons, which is moderately heavier than the industry trend for onshore fiberglass blades of this size, and significantly heavier than blades that contain carbon fiber. A heavier blade could imply some conservatism in terms of blade design, but will lead to increased gravity and inertia loads that need to be accounted for in the overall turbine design. DNV has no basis to doubt that these were appropriately considered by AWP, as confirmed by the turbine's type certificate, and consequently DNV does not consider the blade weight to pose a risk to the blade or turbine design.

The blade for the AW125 (AW61.2-1 or AW61.2-2 for IEC IIIA/IIIB or IIB, respectively) and for the AW132 (AW64.7-1 and AW64.7-2 for IEC IIIB and IIB, respectively), were also designed by AWP using similar principles and blade structure as the AW56.7 blades. Figure 3-2 shows a cutaway of the AW61.2-1 blade design. These blades are produced using the same main mold (up to R48) as the mold used for the AW56.7 blade, with appropriate mold “add-on” for the remaining portion of the blade. On the one hand, the use of the same main mold may imply a small lack of optimization of the blade profile for some of the blades, potentially leading to reduction in energy output[1] on the order of 0.5% or less compared to an entirely new aerodynamic profile. However, AWP considered that this small reduction is offset by a variety of benefits, including the reduction in cost (since only one main mold required for all blade models), flexibility in production (changing production from one blade type to another takes approximately one week with this approach, while changing a complete tooling line would normally require between one and two months) and advantageous lead time.

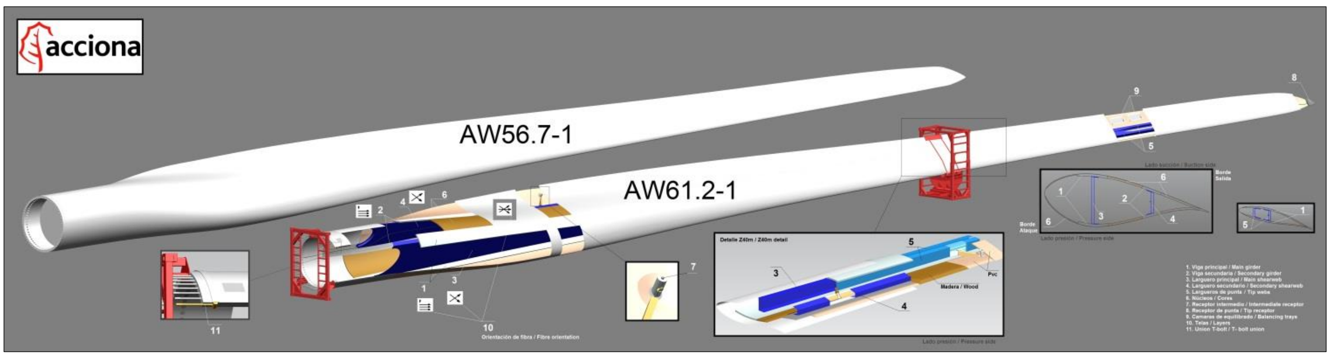


Figure 3-2 AW61.2-1 blade design

DNV reviewed both the AWP blade design and manufacturing processes [6][7], including detailed discussions during a visit in June 2014: this design review was conducted in the AWP engineering offices in Spain, and included presentations by AWP, interviews with blade design engineers, and review of blade design and testing reports requested by DNV. Specific design information reviewed includes; analysis methods, materials used and associated design properties, design margins against various failure modes (e.g., static and fatigue for laminate, buckling, etc.), and analyses performed for various known features in the blade. The AW design tools and methodology were found to be consistent with typical industry practice. Design values for laminate strength were found to be reasonable, and the reported design margins adequate.

AWP developed the blade design in partnership with We4ce from the Netherlands, as well as Garrad Hassan & Partners (now DNV[2]) from the UK [8]. Airfoil wind tunnel testing has also been done at the TU Delft laboratory in Holland and at the HDG laboratory in Germany. DNV also visited AWP’s Lumbier blade manufacturing facility in Spain and TPI’s blade facility in China, as discussed in Sections 2.3.3.2 and 2.3.3.3, with an overall finding that manufacturing practice was on par with industry norm.

[1] This potential reduction in energy production is intrinsically included in each turbine’s power curve.
[2] The entity (Garrad Hassan) that was involved in the design now shares the same parent company (DNV) as DNV Renewables Advisory, the author of this report. DNV Renewables Advisory is a separate business line; no information about the design is shared between the business lines.

AWP structurally tested the AW56.7 blade to static failure, with loads going above the levels required to meet certification requirements. Failure occurred significantly above the target (certification) test load. The span-wise location of initial failure and magnitude of corresponding load were well-matched by predictive calculations, with the result of verifying static structural robustness of the blade as well as validating static structural analyses. AWP also performed material and laminate testing at IMA (Germany) and WMC (Holland), where both standard and cold climate laminate testing has been done.

The AW61.2-1 blade has the same structure as the AW56.7 blade for the first 43 m of the blade, which represents more than 70% of blade length[3]. Furthermore, because it is certified to a lower design class, the (inboard blade) design loads for the AW61.2-1 are within the loads envelope of the AW56.7 blade. As such, AWP's perspective was that there was no need to perform static testing of the AW61.2-1 blade, and the static test performed on the AW56.7 was sufficient for the certification of the AW61.2-1 blade.

AWP has also developed a Class IIB variant of the AW125 (using the AW61.2-2 blade) which uses the same molds but has a slightly modified internal structure. This blade underwent static testing in July 2014 and the first full design conformity statement was obtained in September 2014. DNV reviewed this design development and finds it to be a minor change from the previously verified blade model. AWP reports that the AW61.2-2 variant of the blade is used in all AW125 wind turbines produced since 2016.

For the AW132 blade, AWP originally developed a "straight" blade based on the same aerodynamic profile as the blades for the AW125 and AW116. This blade (known as AW64.7-1) was static tested and had obtained design certification. However, and as a result of the merger with Nordex, AWP decided to incorporate a "pre-bent" geometry in the tip section of the new AW64.7 blade design (AW64.7-2). AWP reports that this facilitates a lighter overall design for the blade and also reduces loading in certain load cases to allow for an upgrading of the class of the wind turbine to IEC IIB. DNV received and reviewed the test results for the AW64.7 blade, and while some repairs were performed during the test, in DNV's opinion the test demonstrated the structural capability of the blade to industry-typical standards.

The industry trend is to move to larger blades to increase capacity factors in low wind speed sites, but this trend has not been without risk. DNV has seen issues with several manufacturers' blades as they increase the rotor diameter of the turbines. Larger blades imply new technical challenges and as such there has been a learning curve in developing the designs and manufacturing process to manufacture these large structures. As such, DNV sees a low-to-moderate risk with large rotors until enough experience has been gained to demonstrate the stability of the new processes.

All blades are fitted with lightning protection systems, see Section 3.6 for details.

See also Sections 4.6.2.4 and 4.6.2.5 for discussion of known blade issues.

3.2.1.1 Edgewise Vibrations

Throughout the wind industry, DNV has observed cases of blade damage in various turbines with large rotors due to resonant edgewise vibration in standstill conditions, henceforth called simply "edgewise vibration". Edgewise vibration is a phenomenon where blade displacements increase due to resonance. If edgewise displacements increase enough, extensive blade damage may result. Edgewise vibration may arise

[3] While the IEC standard recommends that as much span as practical be tested, the GL guideline indicates that a minimum of 70% of blade length needs to be tested.

due to a number of factors, such as vortex shedding and various structural characteristics of the blade. Edgewise vibration is challenging to predict analytically and may not be exposed in Type Approval testing.

The AW3000 is starting to build a track record, and AWP advised that no damage due to edgewise vibration has occurred to date through its AW3000 fleet of turbines. AWP further advised that at a 40-turbine project in Brazil, there was a delay of approximately 50 days (on average) between the time each turbine was mechanically complete (at which point turbines are fully erected and put in idling mode without being energized) and time of commissioning (when the turbines were energized and started to produce power). The yaw system of the turbines would not be active during this time. This "stand-still" period occurred between October 2013 and February 2014, depending on the turbine, which is a windy season at that site (wind speed average above 8 m/s during this period, including multi-directional winds). During this period, some of the turbines are likely to have experienced the combination of conditions (medium winds and considerable misalignment between nacelle orientation and wind direction) that may be favorable to generating edgewise vibration. While this cannot be considered to be a confirmation that the AW3000 blades are not susceptible to edgewise vibration, the lack of reports of damage at this site is seen by DNV as a positive indication.

Edgewise vibration is a low probability of occurrence but high consequence of failure event. As such, in general DNV considers edgewise vibration to present a low to moderate risk for a new, long blade design, until the blade gains a significant operational track record. The operational experience gained at a Brazilian site is one indication that risk of edgewise vibration may be lower in the AW116/3000 blade than in other blades of similar length.

3.2.2 Hub and pitch system

The turbine uses a spherical cast ductile-iron hub, similar to most other current turbines. Each blade is connected to the hub using a four-point contact, double-row ball bearing. This is now the industry standard for variable-pitch turbines. The bearings are grease lubricated, with an automatic greasing system option to ensure that they have adequate lubrication at all times.

The AW3000 pitch system is similar in concept to that used by the AW1500 turbines: it uses a hydraulic system, both to adjust the pitch of the blades in operation above the rated wind speed and for aerodynamic braking. A hydraulic power unit is located in the nacelle and connected to the hub, using a rotating union mounted at the rear of the gearbox. The pitch control valves and associated equipment are mounted in the hub. Hydraulic accumulators are mounted in the hub, to provide failsafe operation of the pitch system during grid loss conditions.

The turbine uses collective pitch, i.e. same pitch control value is sent to all three blades. The pitch system has the capability to adjust the blade pitch angle cyclically, although this type of pitch control is not currently in use on the AW3000 turbines.

DNV understands that an endurance test was performed on the pitch actuator. DNV notes that this test was not an endurance test of the blade bearing, since no blade loads were applied to the blade bearing. However, DNV views the fact that AWP performs design verification endurance bench tests on sub-systems as an indication of AWP's effort to improve reliability.

See also Sections 4.6.2.1 and 4.6.2.9 for known issues with the hub and blade bearing.

3.3 Nacelle components

3.3.1 Main shaft and bearings

The main rotor shaft is supported by two spherical roller bearings, in contrast to the traditional arrangement used by a number of other manufacturers: a single main bearing, with the gearbox low speed shaft bearing providing rear main shaft support. The main advantage of using two main bearings is that non-torque loading on the gearbox housing is minimized. Reduced non-torque loading means that there is less load (and deflection) reacted through the gearbox housing. This may be beneficial to the operation of gears and bearings. A secondary advantage of the bearing arrangement is that the gearbox may be removed from the turbine without removing the rotor.

Spherical roller main bearings have had substandard reliability issues in some other turbine manufacturers using a "three-point mounting arrangement" with a single main bearing; however, DNV is not aware of main bearing problems in AWP turbines and does not consider this specific design feature to be a risk.

An automatic greasing system for the main bearing is available as an option.

3.3.2 Gearbox

Table 3-3 presents a summary of the gearbox configuration for various AW3000 wind turbines (others available).

Table 3-3 Summary of gearbox configuration, 50 and 60 Hz turbines

	AW125/3150	AW132/3300	AW132/3465	AW140/3000
Suppliers & certified model number(s)	Moventas: PPLH-2900.2	Winergy: PZAB 3500		Winergy: PZAB 3500 Moventas: PPLH-2900.2
No. of stages	3			
Stage configuration	2 planetary stages, 1 parallel stage			
Gear ratio	1 :92 (50 Hz) 1 :110 (60 Hz)	1:97 (50 Hz) 1:117 (60 Hz)		1 :103 (50 Hz) 1 :124 (60 Hz)
Planetary bearing type(s)	Cylindrical roller bearings			
Cooling configuration	Oil-to-air heat exchanger			

The input stage is planetary and has four planet gears, contrary to the more commonly used three planet gears. DNV has recently seen some increased use of gearboxes with 4 planet gears as opposed to the typical 3 planet gear configuration in the low speed planetary stage of larger turbines (3 MW range). While this is a departure from the typical configuration, it is not unexpected and is an effective way to handle increased torque with the higher capacity turbines. One of the primary risks with using 4 planets, as opposed to 3, is the increased variability in load sharing between the individual planet gears. This concept is covered by the gearbox design standard IEC 61400-4 to which these gearboxes are designed and tested to.

AWP uses two suppliers for its gearboxes: Moventas and Winergy, both experienced suppliers to the wind industry. Each of these suppliers has decided to address the increased variability in load sharing with a different solution. Moventas uses a "flex pin" concept, patented by Moventas under the name FlexSpider [9], while Winergy does not use flex pins and instead has a solution that allows some movement of the planet supports.

Moventas' solution to the load sharing challenge includes mounting the planet gears on flexible pins which permits the planet gears to maintain alignment under variable torque loading, thus balancing the asymmetrical load between the planet gears. The use of flex pins permits Moventas to deliver a lighter and more cost effective gearbox design when compared to an alternate design where the design torque value is increased to account for the load sharing uncertainty.

The flex pin concept was first used in a prototype wind turbine built in Scotland in 1987, which was decommissioned in 2000 due to a failed generator, and only normal wear and tear was reported in the low speed planetary section. The use of flex pins in wind turbine gearboxes has a limited track record but was validated by GL in 2007 and according to AWP and Moventas, there are more than 600 wind turbine gearboxes with this technology currently in service. As of Q1 2017, AWP reports that only six gearbox failures have occurred on their entire AW3000 fleet, three of which were repaired up-tower. DNV is of the opinion that the use of flex pins permits an optimal gearbox design but the long term effects of the flex-pin technology in the wind industry remains unknown. Because of its relatively short track record, DNV considers the use of the flex pin technology in the first stage of the AW3000 gearbox to represent a low to moderate level of risk, until a significant track record has demonstrated the long-term effectiveness of this technology. Some confidence in the design is gained by reviewing the endurance test results, which were positive, although DNV notes that the endurance tests performed were not equivalent to a 20-year equivalent loading. AWP appears to have developed a reasonable approach to validate gearbox designs in a cost-effective manner to perform bench test (endurance tests) with results that should be indicative of field experience, although DNV considers a 20-year equivalent endurance test to be industry best practice for wind turbine gearboxes. In this test, it is possible to verify the entire gearbox subsystems (gears, bearings, lubrication) reliability and evaluate whether fatigue related failure modes, such as micropitting, are present in the design. DNV considers that recent improvements in endurance testing techniques have incorporated non-torque loading such as thrust, shear, and veer. DNV acknowledges that there are design verification limitations for a 20-year equivalent endurance test in that trade-off need to be made related to gearing failure modes when defining the test parameters. The degree of torque (over-loading) applied and number of cycles that would be needed to e.g. verify gear tooth bending fatigue life vs. pitting fatigue life, according to the design specification, is left to the designer. Nevertheless, there are accepted methods for developing such test protocols.

DNV notes that the IEC turbine design standard does not yet address requirements for non-torque loading test protocol; non-torque loads can have significant impact on gearboxes' reliability, although AWP's use of two main bearings should greatly limit the extent of non-torque loads reacted within the gearbox. DNV considers wind turbine drivetrain design that includes two main bearings, such as the AW3000 turbines, to be beneficial in terms of gearbox reliability.

While it has started to build an operational track record that shows positive indications (only six failures to date, three of which were repaired up-tower), the AW3000 gearboxes do not yet have a long term demonstrated track record. The risk associated with the AW3000 wind turbines' relatively new gearboxes may be further mitigated through commercial arrangements such as an extended warranty term for the turbine.

AWP reports that Moventas is developing a new gearbox version with 20% more torque density and a 10% reduction in size. The new features of this gearbox will include specialized gear materials, cylindrical roller bearing raceways integrated into planet wheels, optimized castings, and optimized lubrication and cooling systems. AWP advises that this new gearbox will begin to be supplied in the AW3000 platform in the near future. DNV has not reviewed this gearbox in detail. AWP also reports that it is currently working with Winergy to develop a new improved gearbox design.

On 30 October 2015, DNV had a webinar with AWP Engineering to discuss the design, testing, and operational experience with the Winergy gearbox. The Winergy gearboxes also use four planets in the first planetary stages, and optimize load sharing between these four planet gears using a flexible sun pinion coupling between the two planetary stages and optimized gear geometry on the ring gear and sun pinion. The associated K-gamma (gear mesh) factor which accounts for load distribution between planets was obtained through direct measurement during prototype testing. The design and approach to optimizing load sharing between the planet gears is in accordance with the IEC 61400-4 Ed.1 gearbox standard. The Winergy gearbox successfully passed its' endurance test in 2010 with no signs of fretting corrosion on the flexible sun pinion coupling which was of primary concern given this particular gearbox arrangement. AWP reports there are 47 Winergy PZAB3535 gearboxes in service with no operational issues or concerns reported (the oldest gearbox was installed in September 2012).

While Winergy has extensive experience using this design in other gearboxes with 3 planet arrangements, the use of 4 planets is an evolutionary change for the wind industry which requires operational monitoring to ensure there are no latent design, quality or operational issues with this particular approach. DNV therefore recommends the end of warranty inspections include borescope inspection of all Winergy and Moventas gearboxes to ensure any latent issues are covered under warranty. DNV considers the level of risk to be similar with the Winergy and Moventas gearboxes.

In addition to experience with AW1500 turbines, AWP has benefited from experience obtained from Acciona Energy's operation of other turbines not manufactured by AWP. AWP also uses experience from the Acciona-owned company, SoMeTec (Soluciones Mecánicas y Tecnológicas, S.L.). SoMeTec has carried out gearbox repairs for AWP and has thereby enabled AWP to incorporate operational experience into their design.

Operating experience with other designs convinced AWP to pay close attention to the cooling and filtration of gearbox oil in order to minimize lubricant related gear or bearing problems. The gearbox cooling and filtration systems have been designed and supplied by the gearbox manufacturers. AWP has chosen to operate the gearbox at relatively low lubricant temperatures. This increases oil viscosity and, if all other factors are equal, extends gear and bearing life.

DNV reviewed test reports from endurance tests on both the Moventas and Winergy gearboxes. The tests included the following:

- Operation at 200% torque levels;
- Overall test duration ~200 hour, without failure;
- Frequent visual inspection and oil sampling;
- Disassembly after testing and detailed checking;
- Tooth contact pattern;
- Lubrication testing; and
- Temperature testing.

Conclusions from both endurance tests, including disassembly and inspection, indicate normal wear of gear teeth and bearings. Load distribution was evaluated using strain gages at the gearbox rings and planets during the endurance test. Results indicated good load distribution.

The gearbox in the prototype turbine has also been subject to inspections, including boroscopy. According to AWP, the endurance testing and inspections have not revealed any technical issues with the gearbox design. DNV finds that this provides some verification of design adequacy for the gearbox design.

AWP has also tested the gearbox start-up procedure at extremely low temperatures (-40 C) for use in the design of the cold climate version of the turbine.

Every gearbox in serial production is subjected to an 8-hour, no-load spin test, including monitoring for vibration and noise characteristics.

See also Section 4.6.2.3 for a known gearbox issue.

3.3.3 High-speed shaft brake

A hydraulic disc brake and a mechanical locking system are mounted on the high-speed shaft. The service brake is normally used for maintenance purposes only. All primary braking of the rotor is provided by blade pitching.

3.3.4 Generator and power convertor

Table 3-4 presents a summary of various generator configurations in the AW3000 wind turbines [10].

Table 3-4 Summary of generator configuration

Model	AW125/3150	AW132/3300	AW132/3465	AW140/3000
Generator rating [kW]	3,390		3,555	3,050
Type	Wound Rotor DFIG			
Voltage [V]	12,000			
Generator suppliers & certified model number(s)	See certifications			
Frequency (of stator)	60 & 50 Hz			
No. of poles	6			
Rated speed [50 Hz, 60 Hz]	1,200 ; 1,440		1,220; 1,464	1,200 ; 1,440
Insulation class	H / H	F / H	F / H	H / H
Protection	IP54 (slip ring unit IP23)			
Type of cooling	Air-to-air cooled			

1. Not included in all certificates

The generator is a doubly fed induction generator (DFIG), with a power electronic converter connected to the rotor to enable a variable speed range of approximately 30% of nominal rotor speed. This is now conventional technology within the wind industry.

The generator stator is rated at 12 kV (i.e. medium voltage). This is a rare concept for wind turbine generators, as they usually generate at a low voltage (690 V is the most common). Medium-voltage generators are used in other industries and can be considered a low risk innovation. AWP originally decided to use a medium-voltage generator based on its experience with small-scale hydro, in order to minimize the levelized cost of energy. The AW3000 generator concept is similar to that used in the AW1500 turbines. Potential advantages and disadvantages of medium-voltage generators are as follows:

Advantages:

- Electrical-resistive losses in the generator are reduced relative to low voltage designs;
- For projects with 12 kV collection system, there is no need for step-up transformers at the turbines; in this case the transformer cost, space requirements, electrical losses and reliability risk may be avoided (see discussion below); and
- Cables (from nacelle to tower base) and their support system can be significantly lighter, cheaper, and may experience reduced electrical losses. However, this benefit can also be obtained by using a low-voltage generator and stepping up to medium voltage in the nacelle using a nacelle-mounted transformer.

Disadvantages:

- Generator capital cost is likely to be higher;
- Capital cost of the switchgear and related components is higher (the AW1500 uses a 12 kV contactor and fuses); and
- Medium-voltage switchgear is required in the base of the turbine, requiring personnel who are trained and qualified for medium-voltage switchgear operation. This has a cost impact for 24-hour staffing and response.
- Higher voltage design requires thicker winding insulation materials which, in turn, reduce heat flow. This aspect must be considered in the generator cooling system.
- Higher potential machines will have higher short-circuit current (torque) magnitude.

The generator rotor operates at a low voltage (690 V), enabling the use of a low-voltage power converter. The converter is understood to be similar to those used on other DFIG wind turbines. A transformer is located between the 690V power converter and the 12 kV systems in the tower base (one floor above tower entrance). This transformer also provides power for the turbine auxiliary systems.

The turbines are supplied with generators manufactured by either ABB or Indar Electric (a branch of the Spanish industrial group Ingeteam). Indar has a significant track record in supplying generators for wind turbines and has supplied medium-voltage generators for AW1500 turbines. Procedures for working inside the wind turbine need to comply with any statutory requirements for working close to medium voltage equipment; this is taken into account when setting up arrangements for operation and maintenance. The same situation is already faced by those turbine manufacturers that provide transformers as an integral part of the turbine, whether in the tower base or in the nacelle.

See also Sections 4.6.2.8 and 4.6.2.12 for known generator and converter issues.

3.3.5 Main frame

As with most megawatt-scale turbines, the AW3000 frame is composed of two parts: the main frame and the generator frame. The main frame is a single casting, with the generator frame bolted to it. The low-speed shaft and main bearings, gearbox, hydraulic power unit and yaw gears and bearings are supported directly by the main frame. The generator frame is made of welded steel.

3.3.6 Yaw system

A slewing ring bearing is used to connect the tower to the machine bedplate. The bearing allows orientation of the rotor into the wind. Turbine orientation is controlled by six electrically drive planetary drives. The yaw system includes hydraulically operated caliper brakes, holding any nacelle position, as required.

3.4 Tower

The AW3000 is available at hub heights of 82 m, 84 m, 87.5 m, 92 m, 105 m and 112.5 m with a tubular steel tower – specific rotor sizes are associated with certain hub heights. It is also available with concrete towers at hub heights of 80 m, 100 m, 120 m and 137.5 m, as discussed further below.

3.4.1 Concrete towers

The use of concrete towers is uncommon in North America, although it is gaining popularity among manufacturers for the new generation of multi-megawatt turbines and taller hub heights. AWP advises that a reduction in cost of energy can be achieved by using a concrete tower in certain markets and at sites with higher wind shear values [11]. Steel prices are generally more volatile than concrete and steel towers also have inherent limitations for towers that are taller than 100 m due to limitation in tower diameter (for transport purposes). Concrete towers may also bring some benefit to the turbine design, as concrete towers are generally stiffer than their steel counterpart, thus limiting movement of the nacelle and blades. The increased tower weight may also lead to a lighter (smaller) foundation. In general, DNV agrees that the use of concrete may be an appropriate technical solution to turbine tower design, and it is expected that more and more concrete and steel/concrete “hybrid” towers will be erected in the wind energy industry, as hub heights are increasing.

AWP’s first concrete tower was erected on a prototype AW1500 turbine in 2006. Since this first prototype, AWP has gained significant additional experience with concrete towers on multiple projects, and as of Q2 2020, 84 AW1500 and 768 AW3000 turbines equipped with concrete towers have been installed [13]. AWP’s installed turbines on concrete towers include 80 m, 100 m and 120 m hub heights.

DNV has been informed that no significant design updates to the original tower design have been required since the design modification and establishment of post-tensioning system in 2011. The fleet of installed AWP concrete towers can therefore be considered as representative of the current concrete tower deployment. Based on the information provided by AWP, DNV considers that the AWP concrete tower design has a significant track record of more than 9 years of operation without major issues to report.

The AWP concrete tower is made from pre-stressed 20 m precast shells that are assembled together on site, using AWP’s patented joints, to form 20 m concrete sections, as shown in Figure 3-3. Each 20 m tall section is made from two to five segments or “keystones”. Once assembled, the concrete tower sections can be stacked and complete towers can be assembled in a similar fashion as standard steel tower, although bolted joints are replaced by grouted joints. A steel transition piece, approximately one meter in height, is installed on top of the upper-most concrete tower section. The completed towers are then “topped” with the nacelle, following which the concrete tower is post-tensioned using 6 tensioning cables located inside the tower.

The AWP concrete tower is an AWP design, certified by DNV Renewables Certification. In addition to standard load calculations for fatigue and extreme loading, and the use of FEM analysis for the tower top interface, AWP has performed a full-scale load test on a 100 m concrete tower, using a crane and pulley system to “pull” on the tower top while measuring loads at the base of the tower, using strain-gauges. According to AWP, this test confirmed the results of the analytical stress calculations.

Figure 3-3 AW3000 concrete tower segments

The installation process is limited by wind speed in a similar way that the installation of a tubular steel tower is impacted. Due to its significant weight and overall design, the AWP concrete tower has an advantage over a standard steel tower: according to AWP, the concrete tower can be fully erected with or without the installation of the nacelle on top and can be left as-is, allowing for more flexibility during construction. The expected installation pace for concrete towers is between two and three towers per week per topping crane, depending on the crane strategy employed; this is generally comparable to steel towers, although it should be noted that more manpower and small crane time will be required at the project location to assemble segments together to form tower sections. This could be beneficial for projects with local content requirements.

Although not expected to be a concern in southern US, attention must be dedicated to installations in low temperatures during the grouting process of tower section joints. AWP has advised that the minimum application temperature of the grout can be controlled with adequate tools and through appropriate storage and preparation of materials, and that some concrete towers were erected in Poland in temperatures down to -10 °C .

Similar to steel towers, concrete towers require annual maintenance, consisting mainly in visual inspections of tower segments, joints and the post-tensioning system. Based on a review of the concrete tower maintenance manual [14], DNV expects that maintenance requirements for the AWP concrete towers are similar, in terms of time and resources required, to steel towers of similar hub height.

AWP concrete towers are equipped with real-time monitoring of natural tower frequency though a nacelle-based accelerometer. Any frequencies outside the expected range will trigger an alarm to inform the operator and initiate further investigation. AWP advised that changes to the tower’s natural frequency may occur due to changes to the tower itself, but could also be due to a change of stiffness of the foundation or soil conditions. DNV has been informed by AWP that while this alarm has been triggered in multiple occasions in the overall AWP concrete tower fleet over the years, no cases of significant downtime related to tower frequency alarms have occurred.

At the request of clients, the concrete towers can be painted, although paint is not required by design. DNV notes that while concrete can be designed to resist deterioration during its design service life, resistance to moisture or other chemical intrusion is important. The AWP concrete towers have been certified for a 20-year design life, and therefore DNV expects these items have been accounted for in the design by AWP and independently verified by the certification agency. That said, for operations beyond 20 years, DNV recommends careful review of these aspects to verify whether any additional maintenance could be required to achieve 25 years, 30 years or longer operational life. Additionally, impacts of possible freeze-thaw cycles and thermal stresses that may be induced on sites with significant temperature variations throughout the year should be appropriately considered in the concrete tower design. Finally, with respect to extend life operations (beyond 20 years), while this can be possible, concrete towers present an additional challenge when compared to steel towers: fatigue issues in steel towers will typically appear as cracks in welds, which can, to some extent, be inspected and repaired. On the other hand, the fatigue accumulation in the rebar of concrete towers is not visible and thus significantly harder to inspect and identify potential issues.

AWP has multiple options for procuring and manufacturing concrete towers, including the ability to produce them in-house or using third party contractors. AWP has established several tower production facilities worldwide, allowing them to produce towers through a locally established supply chain. For example, AWP's tower factory in Monterrey, Mexico, has been established in 2014 and further expanded by the addition of a second production line in 2020. AWP can also deploy on-site manufacturing, including establishing a temporary concrete plant and workshop where concrete shells are molded. In addition to potential cost of energy (COE) reductions, this approach can provide substantial benefits where significant local content is mandated. On the other hand, local manufacturing may be challenging in terms of quality control, when compared to manufacturing in a clean, ISO-certified environment. As typical in the wind energy industry, additional safety factors through increased wall thickness are incorporated in the tower design to compensate for some deviation during manufacturing and construction.

In order to ensure consistent quality on a global level, AWP focusses on quality assurance during establishment of the local supply chain and the concrete mixture. The properties of the concrete ingredients such as aggregate, additives and cement, as well as the cured products, are tested and validated, both to meet the global design specifications, but also to optimize the industrialization process and cycling time. For example, the Monterrey, Mexico facility uses forced curing with steam to shorten curing time but also to increase curing consistency (between day and night, and between seasonal temperature variations).

AWP has specific requirements for the tower segments for various process steps, in particular for the concrete compressive strength. During each segment poor, multiple concrete samples are taken and sample "break" are performed at various intervals (7 days, 14 days, 28 days, or as needed). The compressive strength is tested and documented before handling tower segments such as before demolding, transportation, on-site assembly or tower erection. Post-tensioned concrete towers often require a higher strength concrete than, for example, the foundation; however, such strength can be relatively easy to achieve in factory conditions as compared to in-situ construction.

DNV considers concrete towers to be a change from conventional steel towers, and while uncommon in North America, this is becoming a common solution in other parts of the world. AWP has developed a significant track record, with some turbines on concrete towers having been operational for more than 12 years (AW1500 turbines) and 7 years (AW3000 commercial turbines). Furthermore, the turbine’s type certification that includes the concrete tower, along with the full-scale load test performed on a 100 m concrete tower, offers comfort with this technology.

Based on AWP’s significant track record without major issues, DNV considers the level of technological risk associated with AWP’s concrete towers to be on par with steel towers of similar hub heights, as long as tower specifications, in particular concrete compressive strength, are respected throughout the manufacturing, transportation and installation steps, and that the post-tension cables are installed according to specifications.

3.5 Turbine control

3.5.1 SCADA

The SCADA system for any wind project must provide three important functions, namely:

- Facilitate the operation and maintenance of the project;
- Collect data for reporting and for warranty claims, if required;
- Control the wind farm in accordance with the requirements of the grid code.

To date, the SCADA system used on AW3000 turbines is an in-house development [12] based on Siemens architecture.

DNV has reviewed the SCADA system, and considers that the interface is an effective operational tool, capable of collecting data for reporting and warranty claims.

The SCADA system is able to record and download 10-minute data. DNV has analyzed such data and can confirm that data coverage was reasonable, indicating satisfactory operation of the system.

DNV is not aware of the system’s ability to meet the control requirements of the more demanding grid codes with respect to response time but AWP claims its wind turbines have met the grid code requirements in many of the strictest locations where it has installed wind turbines. It is recommended that this aspect be reviewed on a project-specific basis.

3.5.2 Condition monitoring system

AWP offers an optional condition monitoring system (CMS) [15], supplied by Mita-Teknik. AWP indicated that there are two options for monitoring CMS data: 1) direct monitoring by Mita-Teknik, or 2) the project monitoring raw CMS data itself.

The CMS makes use of one tachometer on the main shaft and eight accelerometers (two on the main shaft, four on the gearbox and one for each generator bearing), in addition to monitoring the temperature of the output stage and oil sump of the gearbox. It also includes a metallic particle counter for the gearbox oil.

DNV notes that the success of any condition monitoring system is directly related to the skills and experience employed in the data analysis. DNV does not have sufficient direct experience with AWP’s CMS or Mita-Teknik analysts to confirm the effectiveness of this system.

3.6 Lightning protection

The AW3000 lightning protection system (LPS) is similar to the system used on the AW1500 turbine. As confirmed by the design assessment certificate, the LPS is designed to IEC 61400-24 lightning protection level (LPL) 1, which is the highest rating available [16]. AWP advised that there have been no blade failures due to lightning that could not be repaired up-tower in the entire AWP fleet of turbines, including both AW1500 and AW3000 turbine models; except for an isolated event in Brazil, where, according to AWP, the lightning level was measured above the LPL 1 and was considered a force majeure event. DNV recommends reviewing lightning risk for each project as part of the site suitability assessment.

AWP specifies that the turbine's grounding resistance be below 10 Ω, which is in line with standard industry practice.

3.7 Maintainability

The AW3000 has a number of features designed with maintainability in mind. The two-bearing shaft support allows the gearbox to be removed without rotor removal. As an option, all major bearings (main shaft, generator, pitch, yaw) can be fitted with an auto-lubrication system. The hub can be accessed without exiting the nacelle.

A lift can be installed inside all tower types (optional for the steel tower variants, standard for the concrete towers). DNV recommends ensuring that the proposed lift complies with local health and safety laws. Use of a lift will increase the efficiency of maintenance work and may also offer health and safety benefits to operators.

The nacelle has an onboard hoist with a capacity of 150 kg which is sufficient to lift tools and small components. An optional hoist with a capacity of 500 kg can also be fitted to enable the replacement of larger components (e.g. yaw motors, hydraulic pumps) without the need for an external crane. DNV notes that the 150 kg capacity is significantly lower than what is installed in most other OEM's nacelles. AWP advised that this smaller hoist is actually significantly faster, which allows for more efficient day-to-day O&M in the nacelle, and that the 500 kg hoist can quickly be fitted if required. DNV has not had the chance to observe the installation of the 500 kg hoist, and therefore cannot confirm AWP's statement.

Additionally, the nacelle cover was recently redesigned for improved ease of maintenance, including the ability to remove the top cover for lifting of heavy components. Finally, the bottom of the nacelle cover has a basin shape, such that any fluid leaks will be collected in a central location, and then will flow to a channel and a hose that runs down the tower to a 50 L drum located in the tower base.

3.8 Temperature ranges and extreme weather options

The operational and extreme temperature ranges for the AW3000 are shown in Table 3-5 below.

Table 3-5 AW3000 temperature limits

Item	Standard version	Cold climate version
Operational range [°C]	-10 to +40	-30 to +40

Extreme range [°C]	-20 to +50	-40 to +50

The AW3000 standard weather turbines have an operational temperature range that is certified from -10°C to +40°C with the exception of the AW116/3000 cold climate version which has received a design certificate to operate down to -30°C. AWP currently specifies an operational temperature range of -20°C to +40°C for all of the AW3000 platform. AWP advised that all AWP turbines, including AW1500 and AW3000 turbines, have been operated down to -20°C for multiple years, which offers a good basis of operational experience. AWP further advised that the standard and cold weather versions are structurally identical (made of same material, castings, etc.) and that only controls and additional heaters differ. DNV generally recommend that the operational temperature range be confirmed by the certification agency, but based on the above, DNV considers the lack of certification of the -10°C to -20°C range for the standard weather version to present minimal risk for a project.

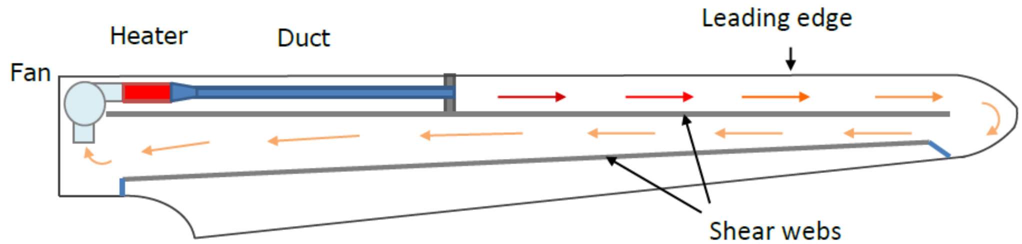
Many of the cold climate AW3000 turbine variants are certified, including the AW116/3000. These variants include the following modifications relative to the standard version [17]:

- Unit heater: 10 unit heaters inside the nacelle and two unit heaters on the tower base are added in order to raise the internal temperature. These unit heaters work independently from the turbine control system and each is controlled by its own thermostat.
- Electrical cabinets: resistance heaters and fans are added in order to adjust the electric cabinet inner temperature and keep the electronics functional.
- Nacelle and nose cone: Changes in ventilation grills and weather seals.
- Switch cabinet: A special switch cabinet is used to ensure proper operation in that temperature range.
- Gearbox: A specific strategy is used for low temperature start-ups.
- Generator: The generator is adapted to the operating temperature range. The heater resistance power is greater than in standard generators and the material of some structural parts and sensors are also modified.
- Hydraulic system: Modifications are made to the oil, oil heater, auxiliary pump, hydraulic unit start-up, and various structural materials.
- Tower: Material changes and an adjustable vent in the door to allow isolation in cold periods.

3.9 Optional blade de-icing system

AWP has developed a blade de-icing system option for the AW3000 platform. Preliminary technical specifications provided by AWP [18] indicate that the system will use re-circulating hot air. A fan and electrical heater installed inside the blade near the blade root will blow hot air inside the blade in order to maintain the blade surface to a given temperature, thus allowing de-icing the blade. As shown in Figure 3-4, the system initially uses ducts and then the intrinsic blade structure (shear webs) to guide the hot air along the blade. According to [18], the power consumption of the system is expected to be approximately 90 kW. The same system would be used for all rotor variants of the AW3000 platform.

DNV will review the de-icing system further, once CFD validation and prototype testing are performed and available for review.



Source: AWP [18]

Figure 3-4 AW3000 flow path for the de-icing system

4 TECHNICAL AND RISK ASSESSMENT

4.1 Turbine evolution

The AW3000 turbine uses the same design concept as the smaller AWP AW1500 turbine. Significant differences include larger rotors (most AW1500 turbines had 70, 77, or 82 m rotors, while the AW3000 has rotors up to 148 m), and a larger drivetrain to account for a 3 MW generator, which doubles the power rating of the turbine as compared to the previous AW1500.

The first AW1500 prototype turbine was an AW60/1300, installed in August 2000 in Spain. By 2002, there was an additional prototype of the AW70/1300 as well as twenty pre-series turbines in operation in Spain. In 2004, the AW70/1500 and the AW77/1500 were introduced to the market. AWP began exporting turbines in 2006, with installations in China, France, and South Korea. The first project to incorporate 60 Hz turbines was the South Korean project in Yangyang, with two 60 Hz AW77/1500 units equipped for operation at low temperatures.

The first AW3000 prototype turbine was an AW100/3000, installed in October 2008 in Spain. AWP changed the rotor on this prototype in 2010 to make it an AW109/3000. An AW116/3000 prototype was installed at CENER in Spain in September 2012; commercial installations began in December 2012 in the 50 Hz market and, simultaneously, two 60 Hz AW116/3000 prototypes were installed in the U.S. An AW125 rotor was installed in Spain in 3Q 2014, with commercial installations starting in early 2015 in Turkey and Brazil. Multiple other prototypes have been installed and operated by AWP since to achieve type certification of the various models in the platform.

It is of note that Acciona Energy is one of the largest owners and operators of wind turbines in the world, operating not only AWP wind turbines but also multiple other turbine types. AWP advised that this experience has been used in the design of the AW1500 platform, and later in the design of the AW3000 platform.

4.2 Certification status

Multiple variants of the AW3000 platform are certified, including cold weather package variants. More than 33 variants have received a Type Certificate[4], affirming that the turbine has been designed, tested, and manufactured according to prevailing standards to achieve a 20-year life when operated within design conditions. In addition, over 40 AW3000 turbine configurations have received design approval (Statements of Compliance or SoC). All certifications have been performed according to the IEC 61400-1 Edition 2 standard, and also reference the "Guideline for the Certification of Wind Turbines" of Germanischer Lloyd (GL Edition 2003 with Supplement 2004 on earlier certificates and the GL Edition 2010 guideline for the most recent certificates – AWP advised that any new certificate would also reference the 2010 version of the GL guideline).

While DNV considers certification to IEC Edition 2 to be acceptable, the more recent edition is preferable. Notable differences that could affect the robustness of the design include a number of added load cases that must be considered, such as extreme turbulence and negative wind shear. IEC 61400-1 ed. 3 was published in 2005, and while it took some time before it was accepted throughout the industry, most turbine manufacturers now use IEC61400-1 ed. 3 for the certification of their wind turbines. AWP indicated that they have considered load cases associated with edition 3. DNV has not reviewed AWP's load analyses in detail.

4.3 Testing

Table 4-1 provides a summary of various tests that have been performed or are planned for the AW3000.

4 Design and type certification of AWP turbines is performed by DEWI-OCC and Germanischer Lloyd (GL). GL Renewable Certification and DNV – Energy, Renewables Advisory (the author of this report) are separate units under the same parent company, DNV. Strict firewalls exist to prevent information sharing between the units relating to turbine designs.

Table 4-1 AW3000 testing status

Test	AW116/3000	AW125/3150	AW132/3300	AW132/3465	AW140/3000
Blade static & fatigue tests	CENER	NaREC (UK)	CENER		
Gearbox endurance tests	WINDTEST	Not planned (not required for certification)	3Q-4Q2018 DEWI	Not planned (not required for certification)	Not planned (not required for certification)
Power curve tests	4Q2013 DEWI; DNV reviewed power curve test results for 50 Hz turbines only	2Q2016 DEWI	3Q2018 DEWI	Not planned (not required for certification)	4Q2018 DEWI
Loads validation	Date and agency TBD. Required and completed as part of type certification				
Noise tests	4Q2012 DEWI (50 Hz); 3Q2013 DNV GL (60 Hz)	4Q2016	4Q2018 Internal measurement (NX), Agency test TBD (NOT REQUIRED FOR GL2010 Certification)	TBD (NOT REQUIRED FOR GL2010 CERTIFICATION)	
LVRT, ZVRT tests	CIRCE	TBD	Date TBD, FORES	TBD	Ongoing (1Q2019, FORES)
Power quality tests	3Q2013 DNV GL (50 Hz); 4Q2013 DNV GL (60 Hz);	4Q2016 DEWI	1Q2019 DEWI	Not planned (not required for certification)	Ongoing (1Q2019) DEWI

In addition to the tests above, AWP reports performing the following tests that are not formally required to obtain a Type Certificate per IEC standards [19]:

- Blades:
  - Materials – Characterization of constituent materials (resins, fibers), fracture-mechanics characterization of bonded joints
  - Short beam three points bending test: inter-laminar shear stress
  - T-bolt joining characterization: subcomponent fatigue and extreme testing
  - Airfoils wind tunnel tests: tests at low and high Reynolds number
- Gearbox: Load distribution test on all four planets
- Hydraulic pitch cylinders: fatigue testing
- Main shaft: Gearbox connection shrink disc - fatigue test of 20 assembly and disassembly cycles
- Blade bearings: Unitary friction test; axial and radial deflection test; test of the seals performance under pressure
- Mechanical brake: Pressure and endurance testing
- High-speed shaft coupling: Fatigue test with nominal misalignment; test with maximum misalignment; axial, angular and torsional stiffness test; maximum reverse torque test; unitary torque limiter setting test
- Yaw drives: Endurance test and static extreme test until breakdown
- Yaw brakes: Functional test with clean and contaminated friction surface; maximum and minimum pressure test; compression and shear tests for the friction pad; seals compatibility test with oil; endurance sword test

- Gearbox & Generator Supports: Unitary static stiffness test; dynamic stiffness test; ultimate load test; fatigue test
- Metallic materials (cast, welded and forged steel components): NDT tests such as ultrasound, magnetic particle, penetrant liquid; destructive tests such as tension and resilience.

DNV finds this level of non-mandatory testing to be equivalent or better than typical industry practice.

4.4 Grid code compliance

This section addresses the AW3000 ability to meet global industry interconnection requirements. Grid code requirements are typically established at the national level, but may be further governed by state/provincial laws as well as county and municipal regulations; generally, the requirements are enforced at the point of common coupling (PCC), and not at the turbine level. The details below are presented for information only; a thorough review of all grid requirements should be performed on a project-specific basis and should include the collection system and substation characteristics in addition to the turbine specifications.

Electrical machines with a doubly fed configuration have been common in wind turbines over the past decade and are generally flexible enough to meet most grid code requirements, with perhaps some adjustments, such as provision of full STATCOM equipment at the point of connection, to ensure compatibility.

Table 4-1 summarizes the turbine capabilities, as presented in the AW3000 Electric Grid data provided by AWP [20].

Table 4-2 Summary table of main grid code requirements – AW3000 wind turbine

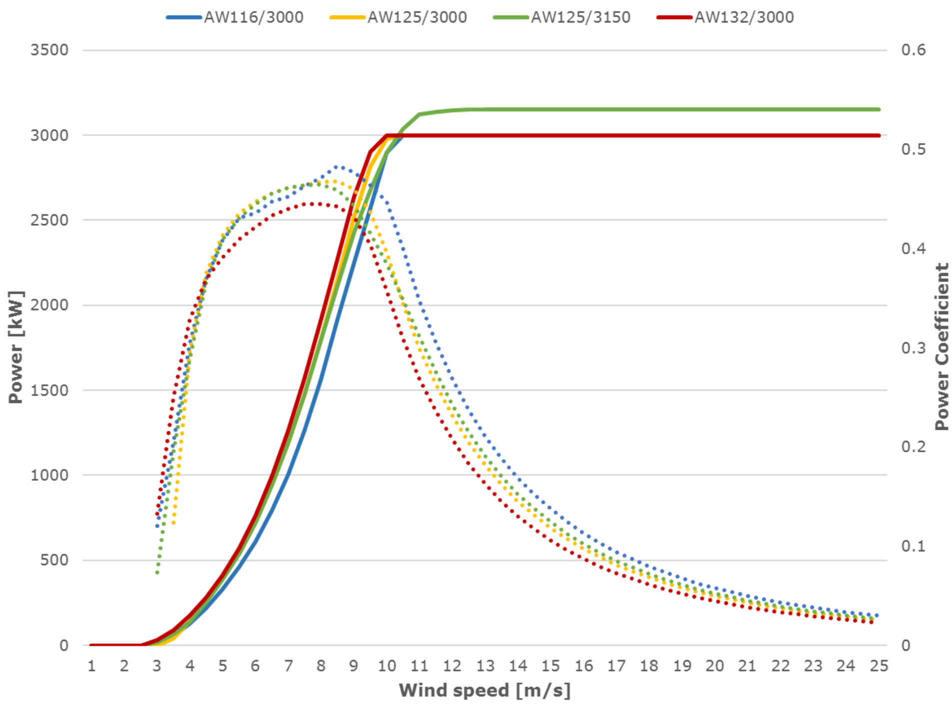
Grid Code Requirement	Comments
Can meet FERC Order 661-A	Capable
Power ramp control	Capable
Reactive power provision	Capable – range 0.93 inductive to 0.93 capacitive, at the 12 kV level
Voltage control	Capable (refer to AWP document DG200032)
Voltage tolerance	Range 12 kV ±10%
LVRT (and ZVRT)	Capable (refer to AWP document DG200032)
Frequency tolerance	±3 Hz on 50 Hz and 60 Hz grid
Generator modeling	PSS/E, Power Factory (DIgSILENT) and PSLF

4.5 Power performance

A turbine model's sales power curve, which is often based on a theoretical calculation, should be verified with independent third-party measurements carried out per the IEC61400-12-1 standard. This section discusses the specified power curve for the AW3000 turbine as well as measured results and their implications for a project.

4.5.1 Calculated power curve

The sales power curve and C_p curves provided by AWP for various AW3000 turbines are presented in Figure 4-1.



Note: the C_p curves shown are "steady state" calculated, and do not include the turbines' internal losses. As such, real C_p curves are expected to be lower.

Figure 4-1 AW3000 sales power curve

As seen in Figure 4-1, the AW3000 turbines appear to have good performance as shown by the high C_p values, on the order of 0.45 for a wide range of wind speeds. Peak C_p values of about 0.45-0.48 were calculated, which would position AWP's C_p values at, or slightly above, industry average. That said, as mentioned above, actual C_p curves may be a bit lower in real life operations.

4.5.2 Power curve verification

DNV has reviewed a total of 21 power curve measurement reports for five variants of the AW3000 turbines. Nine of the power curve tests reviewed have been performed in Spain on 50 Hz wind turbines and followed the recommendations of the IEC61400-12-1 standard. An extract from each test report, including results and in most cases major deviations from the IEC standard, if any, has been made available to DNV for review. In addition, DNV undertook a detailed review of 10-min SCADA data from the 21 power performance tests in order to examine how each tested turbine performs relative to the warranted power curve as both wind speed and turbulence intensity vary. Based on this review, the data show that, on average, the power performance test results were consistent with the sales power curve and show a slight improvement when compared to DNV's site specific loss factor. Based on its review, DNV considers that there is a minimal level of risk that the turbine will not meet its sales power curve, which would have a direct impact on the energy yield of any project. Any risk may be mitigated through successful completion of a power curve test for a project, and/or through an adequate power curve warranty.

4.5.3 Turbine sound power level

Most AW3000 turbine have mean apparent sound power level of 108.5 to 109 dB(A).

If required, AWP indicates that a Sound Reduction Kit option is available which can further reduce sound by 2.5 dB(A) for the AW125 and AW132 variants.

DNV has reviewed high-level summaries of two sound power level measurement reports for the AW116/3000 wind turbine [24]. The first was for a 50 Hz variant, with testing performed in Spain by CENER. The summary report notes that the test was conducted in conformity with the IEC61400-11 standard and no deviations from the standard were noted. The test results show a maximum measured sound power level of 106.5 dB(A). The second was for a 60 Hz version, tested in Iowa, USA, by WINDTEST. The summary report shows a maximum measured sound power level of 107.4 dB(A) [25].

DNV also reviewed three additional sound power level test reports for the 50 Hz variants of the AW3000 platform: one for the AW100/3000, one for the AW109/3000, and one for the AW125/3000. The AW100 and AW109 tests were performed by DEWI in Spain and measurement results showed that these turbines are capable of meeting their specified sound power level [26]. The AW125 test was performed in Turkey by Aresse Engineering and again measurement results showed that the turbine is capable of meeting its specified sound power level [27]. Based on the above, DNV considers that the AW3000 turbines should be able to achieve their specified maximum sound power levels. DNV also recommends that careful consideration be given when comparing measured sound power levels with warranted sound levels. The turbine characteristics are flexible and the turbine can be operated in various modes to limit maximum sound power levels.

4.6 Performance track record and known issues

4.6.1 Installation history

While the first AW3000 prototype, an AW100/3000, was installed in Spain in October 2008, the first 60 Hz prototypes were installed in December 2012, and all commercial installations have occurred in December 2012 or thereafter. As of 14 January 2021, AWP had over 2,491 AW3000 turbines installed worldwide.

The overall installation history for the AW3000 platform is shown in Figure 4-2. The installations include tower heights of 87.5 m and 92.5 m (steel) and 100 and 120 m (concrete), with projects in Spain, U.S., Canada, Chile, Poland, South Africa and Turkey.

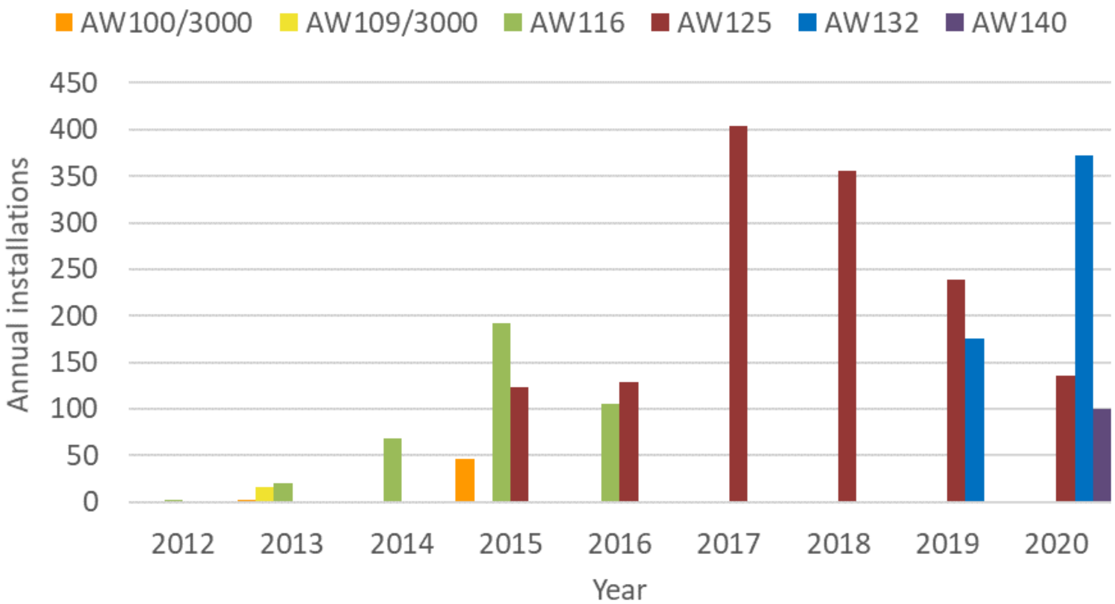


Figure 4-2 Worldwide installation of AW3000 turbines – 14 January 2021 (number of units installed)

DNV also reviewed the history and known issues of the previous AWP model – the AW1500 platform – to help understand lessons learned that may impact future AW3000 turbine performance. Both platforms use similar turbine design concepts, as well as manufacturing and supply chain strategies. As of Q4 2017, 2,736 AW1500 turbines were in operation worldwide. In 2005, 2006, and 2007, the majority of AWP turbines were installed in Spain, although in later years AWP expanded installations to other countries including significant installations in the U.S. and Canada, Latin America, Australia, and China.

4.6.2 Known technical issues

AWP has provided DNV with information about several design changes that have been made as a result of its operational experience [29].

A turbine supplier's root cause analysis process is an indication of the supplier's diligence in addressing issues as they inevitably arise. AWP makes use of the 8D process, which is a problem-solving method that includes, among other things: forming a multi-disciplinary team in order to define containment actions, perform an RCA, correct the problem, and prevent recurrence. Based on discussions with AWP and details about the 8D process provided by AWP on various examples, DNV finds that AWP has generally used a formal analysis process when major issues arise. While it is expected that performing a complete RCA for a complex issue is a lengthy process that can take months to conclude, some of AWP's RCAs have taken longer to complete than typical industry expectations. DNV notes that these RCAs in particular were quite complex and have required extensive field investigation and testing. AWP indicated that a Technical Issues group has been created in 2017 to manage RCAs; this change was made as a result of the merger between Nordex and Acciona.

As examples of the Company's response to technical issues, known technical issues in the AW3000 fleet are outlined below.

4.6.2.1 Blade bearings

DNV has been made aware by AWP of a blade bearing issue affecting AW116 and AW125 wind turbines, where cracks can develop in the blade bearing, eventually leading to blade bearing failure. The AW116 and AW125 blade bearings are supplied by Laulagun and Rothe Erde. DNV understands that to date mainly the Laulagun has been affected by the blade bearing issue. According to AWP, the issue was first observed at an operational wind farm in March 2015, and an RCA was initiated by AWP in April 2015. As of March 2020 and based on information provided by AWP, more than 35 blade bearings have been replaced fleet wide as a direct result of this issue.

AWP has implemented several containment measures for operational projects that have bearings manufactured prior to April 2015, which include the use of reinforcement plates (IRT1017). AWP implemented the IRT1017 reinforcement plates retrofit on blade bearings using the original certified design to help contain the issue. AWP confirmed to DNV that the IRT1017 retrofit has been completed throughout the fleet.

In order to resolve the issue, AWP followed its 8D process, and as part of the process, decided to engage DNV Renewables Certification (DNV RC [5]) to help investigate the cause of failures; this included a review of the manufacturing process and metallurgical analyses by DNV RC. AWP has shared its RCA report [30] in addition to the investigation report undertaken by DNV RC [31] (dated February 2016).

As detailed in the RCA report, AWP reports that most of the blade bearings which have failed developed a radial crack through the outer ring at the centerline of the upper row ball filling bore. Other bearings failed due to development of a radial crack adjacent to the ball fill hole. As reported by DNV RC, the cause of the failures is seen as the result of a superimposition of several macro and micro notch effects, which results in a high stress concentration. Specifically, the ball filling bores in conjunction with the bores for the pin hole and/or the mounting bolt bores are viewed by DNV RC as the decisive macro notches, while the surface roughness within these bores is viewed as micro notches. DNV RC goes on to conclude that the main reason for the cracks is the high surface roughness in the pin hole securing the plug in the ball filling bore and/or the high surface roughness in the mounting bolt bores.

Prior to DNV RC's conclusion, several other contributing factors were identified during the RCA process and included: insufficient material thickness due to the ball fill hole diameter, material inclusions, diametric location of the fill hole in relation to the blade axis, mounting bolt bore size, and corrosion in the mounting bolt holes. As a result of these investigations, several corrective actions were implemented at different stages for newly manufactured bearings which include:

- Factory applied corrosion protection (April 2015);
- First redesigned bearing including increased bearing diameter, decreased ball fill hole diameter and decreased mounting bolt bore diameter (June 2015);
- Modification of ball fill hole location (September 2015)
- Manufacturing process changes to reduce surface roughness in mounting bolt bores (February 2016); and

[5] DNV Renewables Certification shares the same parent company (DNV) as DNV Renewables Advisory, the author of this report, although they are in separate business lines; no information is shared between the business lines.

- Second redesigned bearing with increased outer ring height (March 2016).

DNV has been provided with a statement by DNV RC for the IRT1017 retrofit which applies to the original blade bearings manufactured by Laulagun. DNV RC has reviewed the IRT1017 retrofit and confirmed that the retrofit meets applicable standard's requirements. DNV notes that this only applies to the original blade bearing with the retrofit applied before commissioning or assembled in the factory. In addition, AWP has provided an updated turbine certificate issued by DEWI for the AW125/3000 turbine including the second redesigned blade bearing by both blade bearing suppliers.

With respect to the second bearing redesign, while the surface roughness was reduced in the mounting bolt bores, there is no indication of improvements to the surface roughness in the pin hole, which was identified as one of the root causes by DNV RC. In July 2016, AWP has indicated that they worked with their supplier to improve the surface roughness of the pin hole. Nevertheless, AWP has reported that the design modifications made to the bearing have significantly reduced the stress and improved the overall bearing rigidity. AWP has reported that no issues or field failures have been reported for turbines which have had the bearings manufactured after June 2015 (first and second bearing redesign).

While the design changes implemented in the second redesigned bearing by AWP do not address one of the root causes (i.e. surface roughness in pin hole) identified by DNV RC, the changes to the bearing design, certification, and improvements to the surface roughness of the mounting bolt bores are positive steps in resolving the blade bearing issue. DNV considers the level of risk associated with the second certified redesigned blade bearing to be industry typical, given the accumulated track record.

One of the outcomes of the RCA was to apply a retrofit to turbines in the field to allow continued operation of affected bearings. In late July 2017, DNV received communication from AWP [32] that one failed bearing has led to a catastrophic blade failure in a US project, in which the blade detached from the hub at the bearing interface. It is DNV understanding that one other similar event leading to a catastrophic blade failure has occurred outside of North America, although no details have been provided by Acciona on this second event. According to AWP, the US event occurred on a wind turbine with the original bearing with IRT1017 installed. No apparent cracks with the bearing were noted prior to the IRT1017 retrofit installation. AWP's communication had limited details, other than mentioning that a crack in the outer race was found in the failed bearing. AWP states that the failure was the result of the reinforcement plate not preventing a crack from developing and periodic visual inspection not successfully identifying the development of cracks. As a result of this failure, AWP has developed two additional retrofits. First, an electrical sensor will be installed to automatically trip the wind turbine if any crack were to develop (IRT1110). The second retrofit (IRT1191) contains a series of tensioned cables around the bearing which reduce stress and improve rigidity.

For operational projects with old blade bearing design, DNV recommends ensuring that IRT1017, IRT1110 and IRT1191 are installed on all turbines – AWP has advised that this is the case for the entire fleet. DNV is of the opinion that while the proposed retrofits may reduce the risk of blade bearings failing over the 20 year life, more operational experience will be required to fully confirm their efficiency. DNV currently considers that the originally designed blade bearings in operation, even if all three retrofits mentioned above are applied, have a moderate to high risk of not meeting their intended 20-year design life, and in general, that the fleet of turbines in operation with the originally designed blade bearings has a minimal risk of having other catastrophic failures occurring for turbines where IRT1010, IRT1017 and IRT1191 retrofits have been properly implemented.

DNV presents below its expectations regarding the relative probability of blade bearing failures (i.e. not reaching their intended 20-year design life) for different scenarios and recommends that this be reviewed on a project-specific basis. Given the corrective actions implemented by AWP to date, DNV considers that the risk of catastrophic failures (i.e. blade bearing failure leading to a blade detaching from the rotor) for scenarios #2, 3 and 4 presented below is expected to be minimal.

DNV notes that the replacement of a blade bearing requires the removal of the blade (or the entire rotor), thus in general requiring the use of a crane, making the replacement costly. DNV recommends that appropriate blade bearing repairs/replacements be accounted for in the O&M budget projections and considered in the O&M plan to avoid any significant turbine downtime. Finally, DNV notes that blade bearing issues have affected other OEMs in the past and is generally becoming a bigger challenge with increasing rotor sizes.

Table 4-3 Blade bearing issue, risk assessment

Scenario	Description	Probability of blade bearing not meeting their 20-year design life
1	Original design and IRT1017 + IRT1010 +IRT1191 retrofits applied in the field [1]	Moderate to High
2	Original design and IRT1017 retrofit applied before turbine commissioning, plus IRT1191 applied after commissioning	Moderate
3	First redesigned bearing	Low
4	Second redesigned bearing (including improvement in surface roughness for mounting bolt bores) - certified	Industry typical

1 These bearings may present cracks already; such cracks may be known (observed but considered acceptable by AWP to apply the retrofit) or unknown (too small to have been observed through visual inspection). DNV considers unlikely that such bearings will meet their intended 20-year design life. As such, projects equipped with such blade bearings should expect to replace most, if not all bearings within their project lifetime.

4.6.2.2 Lightning protection system

AWP indicates that during the installation of the first prototype of the AW56.7-1 blades, the LPS was found to be broken after a lightning strike. The down-conductor cables were found to be excessively tight and the connector was found damaged. Following this, the design of the lightning system was reviewed by Global Lightning Protection Systems A/S (GLPS) and it was concluded that there was a risk of breaking the main cable due to an excessively tight connection. Following the design assessment, the following changes were made to the LPS:

- Routing of the main lightning cable: Modified to follow the middle of the shear web, the part of the structure with the least deformation due to the bending of the blade.
- Intermediate connections: The connections in the main cable are flexible in order to accommodate the motion between the different parts.
- Receptors: No problems were found in the blades with previous design, however GLPS noticed that the design could be improved. In the new design, the inner part of the receptor is electrically isolated, with the intent of directing the lightning to be intercepted only by the external part of the receptor.

AWP indicated that additional modifications have been made with the intent of enhancing reliability. The current design involves the new cable routing with no intermediate connections, as well as a single tip receptor. This design has been tested in GLPS's facility and certified by DNV RC.

Through routine blade inspections, AWP also became aware of LPS issues in operating blades and subsequently opened a formal RCA. According to AWP's 8D technical report [55], global fleet inspections were carried out on AW56.7 and AW61.2 blades, and four different failure modes were identified:

- Failure mode 1: Cable lug which connects the main LPS cable at the root to the cross-nut was broken.
- Failure mode 2: Main conductor at Z3.5 displaced from its original position, insulation damage, and in some cases, the cable was broken completely.
- Failure mode 3: Main cable or terminal cable found broken (disconnected) at Z15 or Z30 near Tyco connector.
- Failure mode 4: Main cable insulation damaged at Z0, Z3.5, Z15 and/or Z30, at the end of the over-lamination.

AWP inspected 2,686 blades out of the 3,697 in operation, which included AW56.7 and AW61.2 blades manufactured by Acciona Blades, Aeris, TPI, and Indutch. Of the inspected fleet, TPI and Indutch blades were found to be unaffected by LPS failure modes.

One of AWP's main conclusions is that the braided cable used in TPI and Indutch blades is more flexible and ductile than the non-braided cable used in Acciona and Aeris blades. The RCA identifies the low axial deformation capability of the cable in Acciona and Aeris blades to be a contributing factor in each failure mode, which would explain why TPI and Indutch blades appear to be unaffected by these issues. Further, inadequate cable routing, as observed by GLPS, was identified as one of the root causes for the second failure mode and as a contributing factor for the third and fourth.

Table 4-4 summarizes the RCA findings, identifying the root cause(s) (RC) and contributing factor(s) (CF) for each failure mode as provided by AWP.

Table 4-4 LPS RCA summary for AW56.7 and AW61.2 blades [55]

Cause / Failure Mode	Short cross nut	Extra tension copper wires	Inadequate routing	Abrupt transition over lamination	Laminated edge finishing	Cable movement restriction
Broken cable lug	RC	CF	-	-	-	-
Main conductor at Z3.5 displaced and/or damaged	-	CF	RC	RC	CF	-
Disconnected cable from Tyco	-	CF	CF	-	-	RC

Cause / Failure Mode	Short cross nut	Extra tension copper wires	Inadequate routing	Abrupt transition over lamination	Laminated edge finishing	Cable movement restriction
connector						
Cable insulation damage	-	CF	CF	RC	CF	-

In DNV's opinion it is a reasonable finding that a combination of blade deformation, cable stiffness, and cable routing (e.g., through shear web holes) could produce sufficient strain levels to fail the cable in fatigue. In DNV's opinion, failed cables may introduce the risk of internal arcing, which may increase the risk of fire.

AWP has implemented corrective actions both in the field for existing turbines and in factory for new deliveries. For operating turbines, Nordex has developed two actions which may be applied depending on the presence or lack of a failure. Where LPS system failure(s) are present, Nordex has implemented IMTOC292, which outlines a specific repair procedure for each failure mode. Further, as a proactive mitigation measure, Nordex also developed IRT1462 for blades in which a failure has not occurred, but proactive repairs are deemed necessary, as determined on a project to project basis. IRT1462 includes inspecting the cable lug at Z0, inspecting and repairing insulation damage, and releasing the main cable from the intermediate Tyco connectors at Z15 and Z30 (basically removing the connection between the down conductor cable and the Tyco connectors, although leaving the Tyco connectors and associated terminal connectors on the blade surface).

According to AWP, IMTOC292 and IRT1462 have been validated for each failure mode. Failure mode 1 (broken cable lug) was detected during the beginning of fatigue testing on an AW61.2-2 blade in April 2017. AWP subsequently repaired the cable lug as per IMTOC292 and continued the test, and no further damage was detected following the test, through visual inspection and resistance testing of the LPS. Since implementing IMTOC292 at the end of 2018, multiple blades with a wide variety of failure modes (as outlined above) have been repaired. AWP has re-inspected ten blades six months after repairs were made using IMTOC292 and found no further damage to the LPS. AWP is developing a risk-based inspection protocol for further re-inspections, which DNV considers to be good practice. In early 2020, UL reviewed IRT1462 and concluded that removing the two intermediate Tyco connectors does not affect the existing LPS design. While third-party review and assessment of IRT1462 is a positive step, in DNV's opinion there is remaining uncertainty regarding LPS performance introduced by leaving LPS components disconnected.

The IRT1462 retrofit leaves terminal connectors disconnected. AWP has suggested that the resulting performance of the LPS will not be degraded. The justification for this approach is that later LPS designs have only one receptor at the blade tip, and this later LPS is certified and tested to the same lightning protection level (level 1) as the earlier designs. While DNV acknowledges that most lightning attaches at blade tips, in DNV's opinion, there is still risk that lightning may attach to non-connected receptors. If this occurs, then it is likely that arcing will occur from the terminal cable to the main cable, and structural damage may occur due to the arcing. Successful laboratory testing of a blade with disconnected or broken terminal cables would help alleviate some concerns regarding the approach of abandoning broken branch connections while leaving the terminal connectors on the blade.

Alternatively, removal of the non-tip receptors and terminal cables by cutting holes in the trailing edge panels may be feasible. This would require repair of the structural panels in the blades, however this type of repair is fairly conventional. In DNV's opinion removal of the non-tip receptors and terminal cables would reduce the risk of internal arcing.

For new blades being manufactured, AWP has phased in manufacturing changes related to the LPS. These changes are intended to occur in Acciona Blades, Aeris, and TPI facilities. The timeline of manufacturing changes varies by Phase and blade manufacturer:

- Phase 1: Longer cross-nut used in production at Acciona Blades and Aeris facilities, starting in March 2017 and February 2018, respectively. According to AWP, TPI blades do not have a significant height difference between cable lug and root laminate, and therefore no changes were required.
- Phase 2: Non-braided cable replaced by braided cable in Acciona Blades and Aeris facilities, in July 2017 and October 2017, respectively. All Indutch and TPI AW56.7 and AW61.2 blades have been manufactured using braided cable from the beginning of production; no change is required at these facilities.
- Phase 3: Eliminate intermediate receptors, improve cable routing, change shell-SSW transition to improve transition over lamination, and install a soft transition at the end of over-laminates.

AWP performed a tensile test comparing braided cable to non-braided cable. The test results were shared with DNV. The test results confirmed the hypothesis that the stranded braided cable is significantly less stiff and more ductile, with failure occurring once the braided cable reached 5.9% elongation, as compared to the non-braided cable which failed at 0.6% elongation.

Intermediate receptors were removed in Acciona Blades blades in December 2017, Aeris blades in May 2018, and TPI blades since AW61.2-2 SN°0929. Other Phase 3 improvements were implemented in May 2018 at the Aeris blade factory and in December 2018 at the Acciona Blades factory. According to AWP, no manufacturing changes were required for TPI blades. One full AW61.2-2 TPI blade that included the modified LPS design (containing Phase 1 to 3 manufacturing improvements) was tested statically at CENER in 2019. Visual and resistance testing were performed before and after the testing, and no damage to the LPS was observed. According to AWP, new blade designs (including AW64.7 and AW68.7 blade models) include the same manufacturing improvements. Full blade testing of an AW64.7 blade was completed in 2019, with LPS passing visual inspection and resistance testing before, during, and after the test campaign.

As demonstrated by the operational track record of TPI and Indutch blades, as well as the results of tensile testing and full-scale blade testing, DNV expects the risk of LPS failure modes affecting AW56.7 and AW61.2 blades with braided cable to be industry-typical. It is DNV's opinion that for blades with non-braided cable, and repairs made as per IMTOC292 and/or IRT1462, there is a low risk of LPS failure modes occurring in the future, and risk-based inspections would mitigate this risk to some extent. Once further operational experience is gained, in addition to positive inspection results, this risk level may decrease. For blades with non-braided cables and no repairs or proactive measures taken, DNV considers there to be a moderate-to-high risk of LPS failure modes occurring.

4.6.2.3 Oil Leaks on the outside of the tower

DNV is aware of incidents in North America where AW3000 turbines had oil leaks in the nacelle which reached the base of the tower on the outside of the tower. In all incidents known to DNV, crews were dispatched to clean up the oil and contain the contamination of the ground around the turbine; AWP has indicated that the spills were not of sufficient size to mandate state reporting. AWP advised that it has developed a retrofit to help contain oil spilled in the nacelle. This retrofit is an oil 'drip lip' that is installed in the nacelle to contain leaks within the nacelle and prevent it from running down the exterior of the tower (IRT0998) [33]. AWP indicates that all new nacelles benefit from this design change.

4.6.2.4 Blade trailing edge cracks

DNV is aware of several cracks in the trailing edge of some AW56.7 blades (for the AW116/3000 turbine) and some AW61.2 blades (for the AW125/3000 turbine). DNV has been provided information on this topic in multiple discussions with AWP. As a reminder, the AW56.7 and AW61.2 blades have similar structures for the first 48 m inboard, including same shell geometry, see Section 3.2.1 for details.

Cracking was first found in March 2015 on a single prototype turbine with 56.7 m blades. From April to July 2015, inspections were conducted at all AW116 projects, and cracking was found on multiple turbines. While most cracks were small, some large cracks extended through the blade shell from the trailing edge to the edge of the spar.

From early investigative work into the cracking, AWP indicated that "it has been determined that an initial lot of blades were more susceptible to certain manufacturing deviations (blades produced before 28 May 2013) in a part of a blade with a smaller safety margin in the design." AWP indicates that the affected area is approximately 12 m from the root of the blade and that the affected area is not structural. AWP reports that "an improvement action was made in 2013 (for all blades produced after 28 May 2013) to the blade manufacturing specifications to add additional safety margin in this segment of the blade (slight extension of the layering of the root), which mitigates the impact of variances in the manufacturing process." In short, this means that fiberglass layers were extended to increase safety margins in the design; this was done by AWP prior to identification of cracking issues. AWP indicates that approximately 200 blades were manufactured before the modification and approximately 15% of these blades have exhibited some level of cracking. AWP indicated that all blades produced after 28 May 2013 have the modification and should not be susceptible to this blade cracking mechanism.

The information provided indicates that all cracks found to date are reparable up-tower. Two blade repair procedures (IMTOC0231 & IMTOC0241) [35][36] were provided by AWP, detailing the procedure for addressing cracks that have occurred. According to these procedures, these repairs can be completed up-tower (without needing a crane) either internally, as a provisional repair, or externally, as a permanent repair. Additionally, an inspection procedure was provided which is intended to enable safe operation of turbines with cracked blades [37].

While for a significant period of time AWP has indicated that only 56.7 m blades had been affected, in June 2018, AWP indicated that six cracks on 61.2 m blades have also been detected, although five of them have been determined to be in the blade coating only, and thus considered by AWP to be cosmetic. The sixth crack was found to be in the blade structure. AWP indicated that for the single crack that extended into the blade structure, a manufacturing defect was found where the TE overlaminate was 1.5 m shorter than it was intended to be.

The TE overlaminate in the 61.2 m blade nominally extends to R15, which is beyond the region that was found to be cracking in the 56.7 m blades. AWP's analyses suggest that the longer overlaminate has increased the fatigue margin in the TE to 1.2, which should, in DNV's opinion, reasonably minimize the risk of cracking.

DNV cannot conclude that the changes applied to the blades produced after 28 May 2013, or design updates in the 61.2 m blade, fully eliminate risk of structural cracking at the TE. The precise cause of the cracking has not yet been clearly demonstrated to DNV, however DNV considers blade cracking to be a low risk for Projects with both the 56.7 and 61.2 m designs. If cracking occurs, from DNV's perspective, cracking can be detected with visual inspections that are a part of normal maintenance, and repaired before becoming critical. DNV recommends that Projects budget for ongoing inspection for and repair of a small number of cracks.

Unless further root cause analysis activity identifies a specific Project's blades as being at risk, or until any project blades experience more significant TE cracking, DNV considers ongoing visual inspections (from the ground, with magnification) to be reasonable and prudent. Although insufficient information is available to recommend a specific inspection periodicity, the scheduled maintenance interval should be considered a maximum interval. If cracks do occur, identifying and repairing them early may avoid the need for down-tower repair of a significantly developed crack.

4.6.2.5 Blade main shear web delamination

DNV received communication from AWP on 27 July 2017 [38] indicating that AW3000 turbine blades in operation at more than one project experienced delamination in the shear web flange. This first communication was followed by an RCA status update of the issue provided by AWP in August 2017 [39].

DNV has been involved in multiple project-specific discussions regarding delamination and has also been provided with multiple updates from AWP regarding the RCA (8D) activity [48] between July 2017 and June 2020.

In late June 2018, AWP completed a RCA report [49] which documented the findings of the delamination RCA at the time. In late November 2018, AWP provided an updated RCA report [53] to DNV. This report, combined with DNV's experience and discussions with AWP from the start of the RCA process through June 2020, informs DNV's opinions in this section of the Turbine Review. Below DNV summarizes the problems, followed by discussion of DNV's conclusion, and risk assessment.

AWP started a formal root cause analysis using the 8D process for delamination in July 2017.

Delamination occurs on the trailing edge side of the main shear web, at the corner between the face sheet and flange of the shear web. The red dashed line in Figure 4-3 shows the location of the delamination initiation. Spanwise location of the delamination varies. Both 56.7 m (AW116) and 61.2 m (AW125) blade models have been found with delamination.

Delamination occurs in nearly all cases on the pressure side flange of the shear web. Several instances of delamination have been found on the suction side of the blade, however these instances are far less frequent and may be related to progression of web separation under the shear web (see Section 4.6.2.6 below).

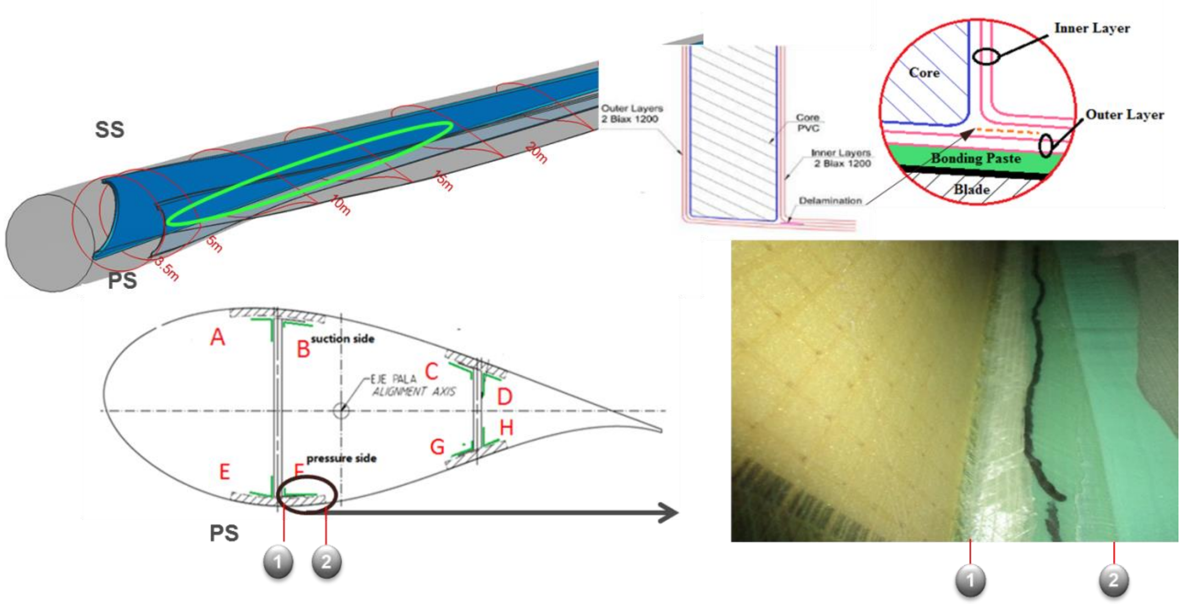


Figure 4-3 Shear web delamination (figure provided by AWP)

AWP's hypothesis is that air bubbles (voids) and a resin-rich area in the corner where delamination appears to initiate are resulting in stress concentrations, and sufficient energy is available to allow the delamination to initiate and progress. AWP's analyses reasonably show that delamination may initiate and propagate under normal loading in the presence of flaws such as voids in the corner of the web flange. In DNV's experience, resin-rich areas in shear web flange corners, and voids in these resin-rich areas, are common in blades, yet delamination at this location due to these features is uncommon. Nonetheless, in DNV's opinion, AWP's hypothesis explaining delamination is generally reasonable, and AWP has identified the contributing factors that are likely leading to the delamination.

Several analyses by AWP lead DNV to conclude that, based on the information available at this time, the fundamental design of the blade is not likely to be a causal factor in delamination. Specific examples of how AWP has substantiated that design is not a causal factor are:

- AWP has conducted finite element modelling to show that Brazier effects (out-of-plane motion of shell panels due to global blade deflection) are well-captured by the linear model used for stress calculations, and that the stresses arising from these effects are within design levels (assuming nominal adhesion and the presence of shear clips). Further, testing of the AW61.2 and AW64.7 blades included measurement of Brazier deflections; results from static testing showed very good correlation between the model predictions and the test results.
- AWP has analytically examined the effect of curvature in the trailing edge of the blade; the analyses are reasonably detailed and suggest that the curvature does not influence the forces and/or stresses that would lead to delamination.

If new relevant information arises, DNV may revise this perspective related to design as a contributing factor to delamination.

For the operating fleet, AWP indicates in their latest RCA document [53] that delamination is a "superficial issue" and will not affect the structural integrity of the blade over its design life. AWP presented analyses and tests to DNV supporting this perspective. The analyses indicate that the blade can meet its design requirements even with extensive (14 m long, full-flange) delamination. In DNV’s opinion, there is uncertainty associated with the supporting analyses and tests relative to expectations associated with real blade operations, although successful completion of a full-scale blade test (discussed below) supports the perspective that the delamination does not affect the capability of the blade to reach its structural design limits.

As of May 2020, AWP completed a full-scale blade test to (in part) assess the effects of delamination on the full structural capability (fatigue and extreme) of the AW61.2 blade model. AWP selected TPI-manufactured blade serial number 1681 and has subjected the blade to pre-fatigue static testing, flapwise fatigue testing, edgewise fatigue testing, and post fatigue static testing. Delamination formed early in the test cycling, grew rapidly in the spanwise direction, and then slowed. DNV has received final test reports produced by CENER which confirm that the AW61.2 blade model successfully completed the full-scale blade testing, with no further propagation of delamination in the post-fatigue static test.

In mid-2018, 61.2 m blade manufacturing processes were modified at all factories to add roving to the web flange corner as means to reinforce the web corner and to minimize the presence of resin-rich areas. AWP’s perspective at that time was that the roving eliminates one contributing factor (resin-rich areas) for the delamination problem. This perspective was supported by AWP’s data indicating that Aeris blades have not experienced delamination, and Aeris blades have included roving in this location since the start of production. Roving does add glass fibers to a resin-rich area of the shear web, and adding fibers to corners in composite structure is a well-known approach to filling potential resin-rich areas. The fibers, however, are primarily oriented in a direction perpendicular to the direction of stresses that would tend to produce delamination, and thus the fibers have limited capability to resist those stresses. It is DNV's perspective that roving may delay initiation of delamination, but the long-term effectiveness of the roving as a solution to the delamination problem is uncertain, particularly given the role that air bubbles (voids) likely play in initiation of delamination.

For new blade models (the 64.7 m and longer), the new shear web design eliminates the flange and thus there is no risk that the specific delamination problem will occur in these blades.

As of June 2020, AWP has advised that while multiple blades have been affected by delamination, no catastrophic blade failures have occurred due to delamination. Further, AWP has conducted over 13,000 risk-based blade inspections (in part with web separation) to better understand the damage mode and track damage propagation, if any.

Despite the presence of delamination in the AW56.7 and AW61.2 blade models, which is not industry typical, successful completion of the full-scale blade test and operating history to date suggest that blades with delamination are capable of meeting their 20-year design life. Therefore, DNV considers the AW56.7 and AW61.2 with delamination present to have industry-typical risk associated with meeting their 20-year design life. Nordex also intends to continue inspecting a limited blade population exhibiting delamination to monitor for any remaining potential issues, although in DNV’s opinion Nordex-Acciona’s inspection protocol (inspecting from the hub rather than via blade entry) will only detect significantly progressed blade damage. Should any findings become relevant to the fleet, DNV expects that Nordex will revise the inspection criteria for AW56.7 and AW61.2 blades exhibiting delamination, and DNV will update this report should new information become available.

4.6.2.6 Blade main shear web separation

DNV was made aware that blades at multiple projects have experienced separation (also referred to as debonding) between the shear web and shell [40]. According to AWP [40], this web separation has been observed in the 56.7 and 61.2 blades. DNV uses the terminology web separation as this term more precisely defines the observed phenomenon. AWP started a formal root cause analysis using the 8D process for web separation in July 2017.

Nordex issued the final RCA on November 12, 2020 [58]. This report, combined with DNV's experience and discussions with AWP, informs DNV's opinions in this section of the Turbine Review. Below DNV summarizes the problems, followed by discussion of DNV's conclusion, risk assessment, and recommendations for risk mitigation.

Web separation occurs along the bond between the main shear web flange and shell. Partial to full separation has been observed from R3.5 to beyond R20. Web separation occurs in nearly all cases on the suction side of the shear web. Instances of separation have been found on the pressure side of the blade, however pressure-side separation is far less frequent than suction-side separation.

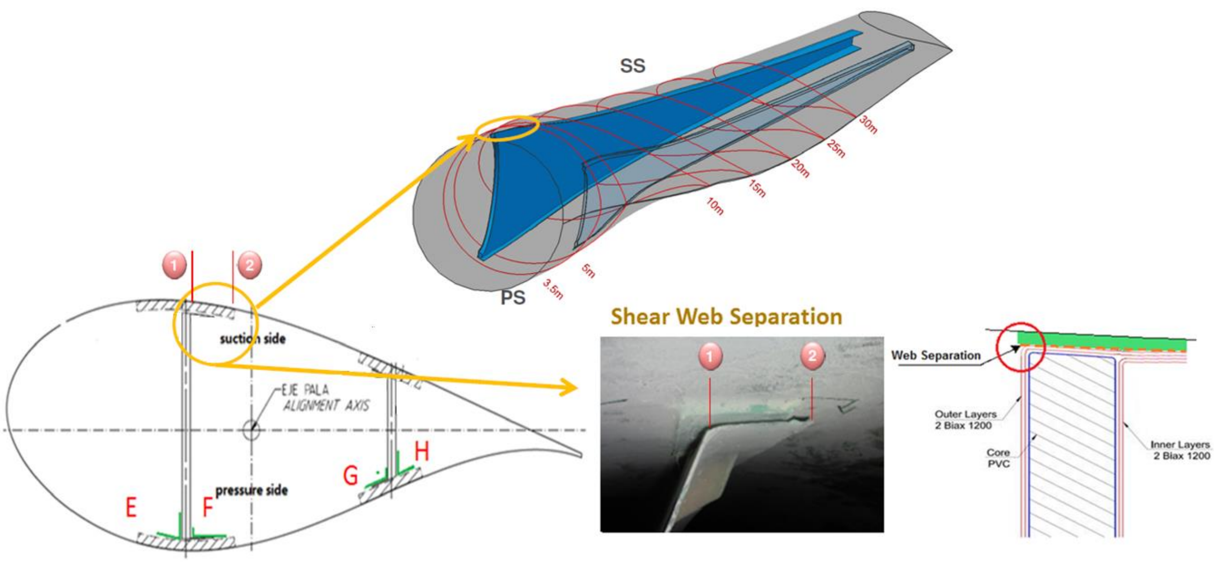


Figure 4-4 Shear web separation (figure provided by AWP)

For web separation, AWP's hypothesis is that a defect in the web-to-shell bond is present, and the defect is of sufficient severity that normal loading leads to crack initiation and progression to web separation. In DNV's opinion, AWP's hypothesis explaining web separation is generally reasonable.

The table below summarizes the root cause and contributing factors as identified in the final RCA report:

Root Cause	Contributing Factors
Relative movement between the adhesive and shear web and subsequent formation of cavities under the shear web	Adhesive mixing ratios, resulting in low Tg adhesive
	Humidity too high

	Surface temperatures too high
	Bonding paste mixing temperature too high
	Priming by TPI
	Excessive mould open time
	Adhesive hardener type, resulting in low Tg adhesive
	High site operating temperature, resulting in reduced mechanical properties of adhesive

Analyses by AWP lead DNV to conclude that the fundamental design of the blade is not likely to be a causal factor. Specific examples of how AWP has substantiated that design is not a causal factor are:

- AWP has conducted finite element modelling to show that Brazier effects (out-of-plane motion of shell panels due to global blade deflection) are well-captured by the linear model used for stress calculations, and that the stresses arising from these effects are within design levels (assuming nominal adhesion and the presence of shear clips). Further, ongoing testing of the 64.7 m blade includes measurement of Brazier deflections; results from pre-fatigue static testing showed very good correlation between the model predictions and the test results.
- AWP has analytically examined the effect of curvature in the trailing edge of the blade; the analyses are reasonably detailed and suggest that the curvature does not influence the forces and/or stresses that would lead to web separation.

AWP determined that movement of the adhesive (relative to the shear web) during the cure process, causes the formation of open cavities in the adhesive. With additional inspection data, AWP strongly correlated the presence of open cavities to blades with shear web separation. AWP provided updates to DNV throughout the RCA process and DNV considers AWP's identified root cause to be generally plausible.

AWP completed a full-scale blade test to (in part) assess the effects of cavities (and associated cracks) on the full structural capability (fatigue and extreme) of the AW61.2 blade model. AWP selected TPI-manufactured blade serial number 1681 and subjected the blade to pre-fatigue static testing, flapwise fatigue testing, edgewise fatigue testing, and post-fatigue static testing. Cracking grew from cavities in the adhesive during the test cycling. DNV has received final test reports produced by CENER which confirm that the AW61.2 blade model successfully completed the full-scale blade testing, including post-fatigue static test, without failure.

As of November 2020, AWP has advised that while multiple blades have been affected by web separation, no catastrophic blade failures have occurred due to web separation.

Stopping rules can be established as a part of any RCA process. The RCA can be determined to be complete when the stopping rules are fulfilled. Establishing stopping rules for this RCA as appropriate identification of contributing factors, and identification of corrective actions that address the contributing factors, DNV concludes that the RCA activities are substantially complete. DNV has reached this conclusion because:

- AWP has identified the root cause that, in DNV's opinion, is leading to the observed damage.
- The root cause is related to materials and manufacturing processes. Evidence currently available suggests that design is not a contributing factor.
- AWP has designed remediations that reduce relevant stresses.

As corrective action for web separation, AWP has implemented multiple changes. For the existing fleet, in DNV's opinion addition of shear clips is a prudent risk mitigation measure against web separation. For new 61.2 m blades, which will have shear clip installed at the factory, various manufacturing changes have been made that are intended to reduce the risk of web separation.

AWP has redesigned the shear web design for the 64.7 and longer blades. Full scale testing of a 64.7 m blade is complete, and state-of-the art methods and an IEC-compliant test approach were used. AWP has gone further than the requirements of the standard and has added measurements of Brazier deflection to the test. AWP was open and transparent with DNV throughout the testing process: AWP shared the test protocol and invited DNV to observe testing and inspect the test blade. Based on the successful completion of the test, DNV has increased confidence that web separation is not a specific risk for the 64.7 and longer blades.

Table 4-5 summarizes DNV's general opinion on risk for the various variants of the AW56.7 and AW61.2 blades for web separation. Project-specific risk levels may differ based on the specific blade population and site conditions.

DNV recommends that commercial risk mitigants be discussed on a project-specific basis. Estimated downtime, loss of production, and other metrics associated with inspection and potential repairs should be accounted for.

Table 4-5 Web separation risk assessment

<table>
<tr><th colspan="2">Variant</th><th>Risk of blades not meeting 20-year design life[1] if no risk mitigation actions are applied</th><th>Risk Mitigation Actions to Lower Risk Level</th><th>Risk of blades not meeting 20-year design life after risk mitigation actions applied</th></tr>
<tr><td colspan="2">All blades without clips</td><td>Moderate-to-High</td><td>Internal risk-based inspections[2] and any required repairs</td><td>Low</td></tr>
<tr><td rowspan="2">All blades with clips to Z11</td><td>No repairs of adhesive geometry deviations beyond the clips</td><td>Low</td><td>Internal risk-based inspections[2] and any required repairs.</td><td>Industry-typical</td></tr>
<tr><td>Repairs made to adhesive geometry deviations beyond the clips and up to Z20</td><td>Industry-typical</td><td>N/A</td><td>N/A</td></tr>
<tr><td colspan="2">Blade with clips to Z20</td><td>Industry-typical</td><td>N/A</td><td>N/A</td></tr>
</table>

1. In the context of this table, "risk of blades not meeting 20-year design life" is the risk that the blades will fail or require significant repair.
2. Initial risk-based inspections conducted with a frequency consistent with Nordex-Acciona document SER_TEC_00_00337 Revision 2. The frequency and population are adjusted based on the inspection findings (e.g. inspections continue until the inspection results clearly show that damage propagation has stopped and fleetwide inspection results clearly indicate that no failures have been reported or significant and relevant repairs have been required). Inspection protocol would include internal blade inspection (e.g. Nordex-Acciona procedure IC0232 Rev A) rather than MREP0064, which inspects only from the hub. Depending on findings, blade repair work may be required. DNV recommends review of the latest revision of the repair protocol (e.g. IMTOC0449 Revision A) prior to implementation of the repairs.

4.6.2.7 Broken blade studs and blade root cracking and delamination

Sixty-four studs (bolts) attach each blade to the turbine. DNV received communication from AWP on 21 August 2017 [41], which indicates that broken blade studs have been observed on 56.7 m blades (AW116/3000) and 61.2 m blades (AW125/3000) at certain wind projects globally. According to AWP, the issue was initially observed in March 2016, and an RCA was subsequently initiated and has identified two distinct failure modes:

- Type 1: Studs failed at the T-bolt thread; and
- Type 2: Studs failed in material away from the thread due to side loading.

AWP's RCA report indicates that the 8D process for Type 2 blade stud failures is complete. According to AWP, Type 2 failures are caused by angular misalignment of the blade during the erection process leading to increased side loading of the studs, and AWP has developed an alignment pin to prevent movement during initial blade installation. DNV finds the root cause determination to be plausible. New projects should confirm with AWP and/or the turbine erection contractor that installation instruction IMC0224 is included as an exhibit to the TSA, that this instruction will be used during erection, and obtain confirmation that the alignment pins are used during turbine erection to control the risk of radial misalignment. AWP has reported no failures since this procedure was implemented, and as such, DNV considers that type 2 failures do not represent a risk to projects where the IMC0224 instruction is confirmed to be followed properly.

For Type 1 failures, according to AWP [43], only blades manufactured in AWP's Lumbier facility ("Lumbier blades") have been affected.

AWP has observed that Type 1 failures mainly occur in two circumferential locations around the blade root; these locations correspond to the highest fatigue loading on the bolts.

AWP has concluded that the flatness of the root face of the blade is inducing bending in the bolts, resulting in stud failure. With the information known to date, DNV concurs with AWP's conclusion.

When a blade stud failure occurs, it is possible that a portion of the blade stud will fall into the hub and cause damage (e.g., to a hydraulic line), which would generally cause a turbine fault. Consequently, it is expected that in addition to the replacement of the stud itself, some repairs and/or hydraulic oil cleaning will be required in the hub. Although this has not happened to date, in a worst-case scenario, should multiple blade studs fail nearly simultaneously, stud failures could continue to progress and separation of the blade from the turbine could occur.

AWP initially implemented the following corrective actions for blades with risk of Type 1 blade stud failures (Lumbier blades):

- Preventative blade stud inspections were conducted on 10% of blades at wind projects where blade bolt failures have occurred; and
- In cases of failed blade studs, four adjacent bolts (two on either side of the failed bolt) were replaced, as fatigue life may be significantly shortened for these bolts.

Additionally, AWP implemented a physical barrier to prevent broken blade studs from falling into the hub and detector sensors (consisting of a thin copper wire) to stop the turbine automatically when a bolt fails. 69 initial sets of the barrier/sensor system were installed to validate the system.

As of January 2021, AWP released a re-designed broken stud detection kit [62] which increases the number of bolts protected and is intended to prevent broken studs falling into the hub. According to AWP, the new version has been installed in one turbine and subsequently validated by AWP in December 2020. AWP plans to apply the barrier/sensor system as a corrective action, and in DNV's opinion, it is reasonable to expect that once troubleshooting of the initial installations is worked out, the containment system will be effective. The system, however, will require maintenance during operations and may lengthen the time required to perform some maintenance activities.

As of December 2020, AWP developed a refined strategy for failed blade studs [61]. The new strategy includes four corrective actions, each of which would be applied sequentially should the stud breakage frequency (or "ratio") at a particular turbine exceed what is considered to be industry typical. AWP has yet to finalize their definition of this ratio. Figure 4-5 presents the sequential corrective actions to be performed if the currently applied mitigation measure at a particular turbine still results in bolt breakage above an industry typical rate. AWP have also informed DNV that the re-designed barrier/sensor system will be installed in conjunction with the corrective actions presented below; whereby this system will be installed with the next-in-line corrective action.

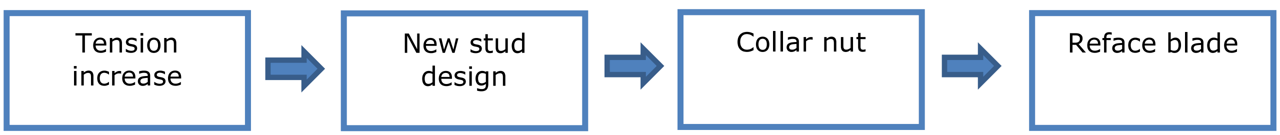


Figure 4-5 AWP corrective action strategy for broken blade bolts

AWP's aim of increasing blade bolt tension is to improve the contact between the blade and blade bearing. More precisely, AWP intends to reach a final bolt pre-tension force of 470 kN for this corrective action; increased from 440 kN. Based on the interim RCA presentation on the topic [56], DNV understands the new stud design will have a coarser thread with improved behavior with respect to fatigue. DNV understands that the collar nut corrective action installs flanged nuts to replace washers and reduce the number of interfaces and corresponding losses in preload due to embedment effects within the bolted joint for a given preload. Should these corrective actions prove insufficient to mitigate bolt breakage, AWP recommends refacing the blade root, which required to bring the blade down tower.

In DNV's opinion, the planned corrective actions other than refacing the blade roots do not address the root cause of the problem, which AWP has indicated is a lack of root face flatness. Further, from DNV's perspective, an "industry typical" number of broken blade studs is near-zero, so by using number of stud failures as a metric for success of corrective actions, AWP has set a high bar for judging the effectiveness of the remediation (other than refacing the roots).

In DNV's opinion, tension increase may delay stud failures, or reduce stud failure rates by reducing fatigue loading on studs. However, increasing the tension in the studs does not address the root cause of the problem, and as such is not likely to eliminate stud failures.

In addition to bolt failures, AWP has found that blades with Type 1 stud failures are experiencing circumferential cracking along the blade root face. AWP has concluded that the circumferential cracking is also due to a lack of flatness of the blade root face.

DNV is also aware of root delamination occurring in some Lumbier blades. These delaminations are present close to the blade root at overlaps between fiberglass layers, where the overlaps are chordwise. While these are possibly unrelated to circumferential cracks, in DNV's opinion it is likely that root delamination is the same damage mode as the circumferential cracking. Specifically, DNV expects that the circumferential cracking is a delamination viewed on the root face.

DNV and AWP discussed the potential for increased stud tension to increase the risk of initiation and/or propagation of cracking within the blade root structure. AWP has conducted analyses showing that increased bolt preload reduces the maximum interlaminar shear stress (ISS) in the root laminate. While DNV has not conducted detailed calculations, our engineering perspective is that increasing stud tension in a joint with a non-flat blade root face may increase ISS within the blade root. It is possible that increasing the tension increases ISS in some localized areas of the root, and decreases ISS in others. In DNV's opinion, there is likely to be variability in the consequences of tension increase, depending on the extent and severity of cracking and lack of flatness.

For blades with circumferential cracks along the blade root face and/or delaminations within the blade laminate, AWP, in cooperation with CENER, conducted finite element modelling to understand the potential for circumferential cracks and delaminations to propagate, as well as the structural consequence of delaminations on buckling failure. For delaminations less than 1 m in spanwise extent, AWP concluded that no catastrophic failure is expected, however some local buckling may occur that may increase the risk of crack growth. For delaminations greater than 1 m in spanwise extent, AWP concluded that more investigation is required.

AWP conducted a full-scale blade test in the edgewise direction on a three-year old AW61.2 blade (serial number 0017) that had higher-than-typical blade bolt breakage and circumferential cracking present. This blade also had that had been manufactured using the excess adhesive during lay-up. The blade was cut at Z38 (38 m from the root) and reinforced to reduce the risk of blade buckling away from the root, as the focus of the test was the blade root area and applied loading required to achieve the needed root bending moment created risk of buckling. AWP indicated that the blade test was designed to be representative of both AW56.7 and AW61.2 blade models.

The initial test objectives were to observe crack growth characteristics and to test repairs intended to prevent crack growth. AWP later re-defined the test objectives to demonstrate that the blade is capable of withstanding fatigue and post-fatigue static loads equivalent to 20 years of operation, without the execution of any repair, despite the presence of circumferential cracking prior to the test. Once the test loading sequence was complete, AWP refaced the blade, applied metallic compression pads around the T-bolt connections, and bolted together the first 1 m of the blade where delaminations were present, to prevent growth of existing cracks. AWP re-performed the full-scale blade test in the edgewise direction, by first completing a pre-fatigue static test, followed by fatigue testing, and finally post-fatigue static testing. Instrumentation used during testing included strain gauges, linear displacement sensors, and accelerometers. Periodic ultrasonic testing (UT) was also performed.

AWP provided DNV with a presentation summarizing the results from the first test (before repair). AWP reported no loss of blade stiffness during both fatigue and static tests, and linear behavior was observed at the strain gauges. Through UT inspections performed during testing, AWP observed new circumferential cracks in the root structure. Delaminations at chordwise ply drops in the root structure were found to initiate and grow during testing.

On 25 February 2021, AWP informed DNV that the second full scale blade test in the edgewise direction (with repairs made) was successfully completed, and DNV expects AWP will share the test results when available.

For blades with circumferential cracks and/or delaminations present, AWP has developed two operational strategies based on crack length. For blades with cracks that are less than 1 m in spanwise extent, AWP would run the turbine and conduct risk-based inspections. Blades with cracks greater than 1 m in spanwise extent would need to be evaluated on an individual basis. AWP is in the process of defining the protocol for risk-based inspections and informed DNV that up-tower UT inspections will be included to monitor crack growth.

For new production blades, since January 2019, AWP has conducted flatness measurements in the Lumbier factory on one blade per week (measuring 256 points on the root face) and have found all test results to be within flatness specification. AWP has also implemented ultrasonic testing (UT) inspections on 100% of new Lumbier blades to minimize of risk of out-of-specification root flatness.

For Lumbier blades produced prior to January 2019, DNV considers Type 1 blade bolt failures and circumferential cracking/delamination to have a moderate-to-high risk of occurring. Due to the newer controls implemented on the blade root face machining process, in DNV's opinion there is a minimal risk of Type 1 failures or circumferential cracking/delamination affecting AW64.7 and AW68.7 model blades, non-Lumbier blades, or Lumbier blades manufactured after January 2019.

Despite the analysis and full-scale blade test performed by AWP, in DNV's opinion, operation of blades with extensive circumferential cracks (root damage), plus demonstrated ability to form new delaminations at overlaps, represents an increase in the risk of catastrophic failure relative to operation of blades without root damage.

In DNV's opinion, refacing the affected blade roots to within tolerance would be an appropriate corrective action as it would eliminate the identified causal factor for both stud failure and root cracking. However, for blades with circumferential cracks and/or delaminations present, such damage would remain in the remediated blades. While the ISS related to the lack of root face flatness would be eliminated, some risk of propagation would remain due to normal operational stresses interacting with the initial damage. Therefore, risk-based inspections may reveal that refaced blades will require additional laminate repair to meet a 20-year design life. As an interim measure, DNV recommends implementing all corrective actions (increased preload tension, coarse thread bolts, and collar nuts) until decisions regarding refacing (or re-blading, should a cost-benefit analysis show promise) can be made.

DNV recommends that commercial risk mitigants be discussed on a project-specific basis. Estimated downtime, loss of production, and other metrics associated with inspection and potential repairs should be accounted for.

As of April 2021, AWP's 8D process is still underway for bolt failures and root cracking/delamination. In February 2020, AWP provided DNV with an interim RCA presentation for review [56] which summarizes the status and preliminary findings of the RCA. In June and December 2020, AWP presented updated information to DNV regarding this technical issue, including the results of finite element modelling, full-scale blade test plan and status, and proposed corrective action strategy [59] [60] [61]. These presentations and technical interchanges since then (as recently as February 2021) have informed our perspective in this section of this report. It is DNV's understanding that AWP will continue to update DNV as the RCA progresses and/or new findings are made, and DNV will update this report when new information comes to light.

4.6.2.8 Converter overheating

DNV is aware of converter overheating occurring on some AW116 turbines located in particularly hot climates. AWP advised that only turbines equipped with ABB converter units have been affected by this issue and do not anticipate issues with the Ingeteam converter. AWP further indicates that the Ingeteam converter has different temperature alarm thresholds and heat dissipation characteristics than the ABB converter. The issue is due to the fact that a fan style water cooling system not being able to cool the system below the temperature of the fresh air source surrounding it. Such cooling systems use convection (i.e. a fan) to drive the temperature of the heat exchanger as close as possible to the surrounding air temperature from within the tower base, where temperatures were hotter than expected.

AWP subsequently advised that a permanent retrofit solution is to move the exchanger outside the tower, and has been undertaking this retrofit action for projects affected by this issue. DNV recommends that the Project discuss with AWP to determine if converter overheating is expected to be a concern for the Project's temperature range. Should the solution be to move the heat exchanger outside of the tower, the Project should consider the noise impact of doing so. Constant-speed fans emit pure acoustic tones that can contribute to tone prominence above thresholds usually set according to local ordinances.

AWP has indicated that this issue does not affect Ingeteam converters, as it has different temperature alarm thresholds and heat dissipation characteristics than ABB converters.

4.6.2.9 Hub noise and hub slippage

DNV is aware of a number of AW116 turbines which have exhibited a squeaking noise which can be heard during operation at low wind speeds; this noise is coming from the hub to main shaft connection, and is associated with hub slippage: slippage between the hub and main shaft mating surfaces in the circumferential direction under torsional loading. It is important to mention that no failures have been reported with respect to this issue, although DNV does not consider the hub slippage and consequent noise to be normal behavior of a wind turbine. AWP started an RCA on this issue in Q3 2015, and investigations have been ongoing up to Q1 2018. As of June 2018, AWP now considers this issue to be fully resolved.

For completeness, DNV presents here the different activities and actions taken from 2015 to 2018 by AWP in order to resolve and close this issue. DNV opinions and recommendations are summarized in the "hub noise and hub slippage conclusion" presented at the end of this subsection.

Detailed description and timeline of the issue

Initially, starting in Q3 2015, AWP has investigated the hub noise and hub slippage concern on one of its prototypes and provided a number of associated documents and reports [42][44][45]. These reports identified that the main shaft-to-rotor joint is suspected to be the source of the noise and this was confirmed with noise recordings in a prototype nacelle during operation. A comparison from acoustic noise tests between a turbine with the noise and a turbine without the noise showed baseline noise readings to be equivalent between both turbines. This led AWP to conclude that the noise does not affect the sound power level of the turbine. DNV accepts AWP's conclusion that the noise in itself is not a risk to projects.

In the investigation report for noise [42], AWP noted that in multiple prototype turbines surveyed, a circumferential slippage of up to 2 mm could be observed between the main shaft and hub. One of the turbines (Barasoain A2.1) with a slipped rotor had been operating for 2.5 years and showed superficial scratches on the side of bolts that had been removed from the main shaft-to-rotor joint as a part of the investigation. The report indicates that tests of five scratched bolts from Barásoain A2.1 did not show any cracks or evidence of yielding. Cracking or yielding would be indicators of potential reductions in bolt strength.

The AWP report indicated that the specified preload on the M42 main shaft-to-rotor bolts for the prototype turbines was not achieved using the standard tensioning procedure. AWP identified several actions which could possibly improve the tensioning process but an initial method proved ineffective in eliminating the noise.

In the report [42], AWP has concluded that the main shaft-to-rotor joint has adequate structural integrity, but that the joint can be improved to eliminate the main shaft noise. This report also includes a statement that "The structural integrity of the bolted union is not at risk." AWP's assertion that the main shaft-to-rotor joint is not at risk is supported by investigations described in the Azterlan Report 318255 [44], which DNV has also reviewed.

AWP has further investigated the effect of the slippage of the rotor and possible solutions to prevent the hub slippage. In the provided "Supplemental report to the Main Shaft-Hub noise Preliminary Investigation" dated 13 November 2015 [45], AWP elaborates on the joint design, indicating that the design incorporates elastic spring pins which are in place partly to provide an extra safety function to bear any shear stresses resulting from any slippage of the joint. DNV considers that these pins may reduce the shear forces which could affect the bolts; however, the existence of the spring pins is not sufficient to confirm that there is no risk to the joint when slippage occurs.

In the supplemental report [45], AWP outlines the following activities:

- "Further actions are underway to modify and test the tensioning process." In DNV's opinion, careful control of bolt tensioning to obtain full preload, and re-tensioning to avoid loss of preload due to embedment, are beneficial.
- "AWP is working with the certifying body to prepare calculations on the joint under the reduced preload and modified frictional coefficients to evaluate any impacts to the design loads". In DNV's opinion, confirmation of sufficient joint integrity under out of spec bolt preloads and friction coefficients may allow to confirm whether the joint is at risk or not.

AWP has provided a letter dated December 2016 [46] from the certification agency confirming that based "on data collected and initial analysis, the design of components, design basis, operation and commissioning are currently eliminated from the root cause analysis investigation."

A document indicated to be a root cause analysis report dated 14 December 2017 [51] was provided by AWP concluding their determination of the root cause of hub noise and slippage to be a combination of low bolt preload caused by relaxation due to the elastic properties of the union, and foreign material between the hub and main shaft. Corrective actions include increasing the bolt preload, sealing of the circumferential joint edge between the hub and main shaft, and improved cleaning of the surfaces of the joint before assembly. In DNV's opinion these are plausible conclusions, however, the mechanism causing the bolt preload to relax is not explained and it is unclear whether it is well understood. In general for this type of union, some relaxation is expected but an excessive amount that is not corrected during typical post-construction retightening is cause for further investigation.

AWP has also provided a report from DEWI dated 23 February 2018 [52] concluding the following:

- For the increase in bolt preload to 975 kN "A decrease of the safety margin was observed, which was, nevertheless, within acceptable margins." this statement from the certification agency DEWI does confirm that the increased bolt preload, to 975 kN, is appropriate and within standard's requirements.
- Based on measurements of bolt preload six weeks after tightening to 975 kN the relaxation was approximately 3% and, "the measured and extrapolated relaxation values are considered plausible." DNV assumes that the intent of this DEWI statement is to confirm that the observed relaxation is acceptable, although DNV notes that the language used: "values are considered plausible" is somewhat imprecise.

DNV notes that a post-design correction to bolt pre-load is not uncommon, however an indication that this change does not invalidate the design or type certificate is required. DNV discussed this topic with Acciona on a call on 6 June 2018, where Acciona explains that they go through a review of "known issues" with the certification body on an annual basis. The above-mentioned report [52] is part of this follow-up effort, and Acciona correctly pointed out that the DEWI report concludes that "The increasing of the bolt tensioning load has no negative influence on the structural integrity of the hub – main shaft connection." Further, Acciona confirmed that this report will be referenced in the next revision of the type certificate to be issued in Q3 2018. Based on this, DNV accepts that the change to the bolt preload has been appropriately reviewed and fully approved by the certification agency.

In addition to the above, AWP indicates that it is now performing additional cleaning and sealing actions to the joint interface to prevent any contamination which have been identified as possible root causes. AWP further indicated that the combined actions have so far led to positive results: some recent operational projects, for which these actions have implemented, have shown significantly less noise, although Acciona confirmed that the noise have not completely disappeared.

In addition to loss of or inappropriate bolt preload, there is another concern with slipped or slipping rotors: DNV is aware of a hub slippage issue in at least one other turbine model (not Acciona), which led to shear forces in the joint binding bolts in place, resulting in significant difficulties removing bolts and broken bolts. DNV has not been made aware of this specific issue for any Acciona AW3000 to date, and some of the Acciona reports confirm that it's been possible to remove bolts without any issues for hubs that have shown slippage. As such, DNV considers this concern to represent a minimal risk to Acciona turbines.

Hub noise and hub slippage conclusion

As of June 2018, Acciona has provided a significant amount of information to DNV, including a report from the certification agency DEWI [52] confirming that the new bolt preload is adequate. That said, Acciona has not provided a formal RCA report to DNV, and Acciona has acknowledged that even with the implementation of corrective actions, some of the newer projects still show some of the noise (although to a significantly lower level than before). DNV considers that there are still some "grey zones" in the investigation, including the fact that the joint relaxation mechanism does not seem to be fully understood.

As such, DNV cannot fully support Acciona's conclusion that this issue is fully resolved. DNV considers that low bolt preload and hub slippage can lead to compromised fatigue safety margins in the joint. Initial consequences could include bolt failures, which if not detected and repaired could eventually lead to failure of the connection and the rotor falling to the ground. DNV considers this issue to present a low risk for any given project with AW3000 turbines, especially for turbines that are producing the noise. DNV considers that more recent projects, where an increased bolt preload has been applied, are less at risk.

It is of note that hub slippage or loss of bolt preload will not necessarily occur at all AW3000 turbines: in any given turbine, a demonstration via appropriate measurements that hub slippage or low initial bolt preload did not occur would mitigate this risk for the said turbine. As such, DNV recommends that appropriate measurements be performed on all AW3000 turbines to determine whether hub slippage is occurring or not.

4.6.2.10 Switchgear stator contactor failures

DNV is aware of several incidents affecting AW116 and AW125 turbines where the switchgear's stator contactor failed to open as expected, resulting in damage/fires to the converter or pad mount transformer (PMT). The PMT failure was unique to one project/PMT type and was subject to a separate RCA process, based on which it was confirmed that the specific PMT design at that project was faulty. As such, DNV considers that PMTs at other projects are not at risk of this failure mode as long as they do not have the same faulty design.

Following these incidents, AWP has actively been engaged with their suppliers (Ormazabal switchgear with ABB contactors) to conduct a root cause analysis of the contactor failures. As of February 2020, AWP provided DNV with a Technical Issue 8D Report [57] that summarizes the RCA conclusions and which notes that AWP is not able to go deeper in the RCA due to lack of access to the "know-how" information of the electronic board. According to AWP, the identified root causes are random malfunctioning of the electronic board that generates over temperature in specific components, with a very low likelihood of occurrence; and a manufacturing failure in the energy failure autotrip (EFA) configuration in some of the MACR2 electronic boards. Stator contactors manufactured by ABB (model VSC12 with electronic board model MACR1 or MACR2) are potentially at risk of this failure occurring, where the contactor remains in the closed or intermediate position after receiving an open command. These failure modes may result in an overcurrent event that can cause damage/fires to the converter.

For existing ABB contactors with electronic board model VSC12 in operation, AWP has implemented several mitigation measures for operational projects including feeder breaker protection (temporary), motor-driven actuator (retrofit), an emergency trip release (retrofit), and EFA activation. Aside from the motor-driven actuator and the emergency trip release, these corrective actions are compatible with one another, and the choice of which one(s) should be selected is determined on a project-to-project basis.

<u>Feeder breaker protection (temporary)</u>: DNV is aware of a protection scheme that causes the substation feeder breaker to trip in response to a stator contactor failing to open. AWP has advised that it takes approximately 5 seconds for power converter components to be damaged. DNV considers that the feeder breaker protection scheme is adequate to protect the converter components. However, DNV notes that this scheme, when activated, causes all turbines on a feeder to be taken offline in an emergency mode, resulting in increased downtime and stress to the turbine components. However, DNV notes that accumulated stress may be considered as negligible as according to AWP, this scheme is rarely activated.

<u>Motor-driven actuator (retrofit)</u>: DNV has reviewed the stator contactor motor operated actuator plan developed by AWP. The system is relatively simple, and operates by engaging the pre-existing emergency load-break mechanism of the contactor. The mechanism will be initiated by the same alarm signal used to operate the feeder breaker protection scheme. DNV finds the system sufficiently fast and reliable to significantly reduce the risk of equipment damage in the event of stator contactor failure to open.

In March 2017 and as part of construction monitoring work at a Project, DNV confirmed the successful installation and testing of the motor driven actuator system. At this same Project, DNV also confirmed the feeder protection scheme to be operational as designed.

Emergency trip release (retrofit): DNV is aware of an emergency trip release (ETR) retrofit developed by ABB that is compatible with MACR1 and MACR2 electronic boards. The ETR is an additional PLC board installed on the stator contactor itself which acts as a redundancy as it opens the contactor following an opening command when the opening position is not confirmed. The ETR uses capacitors to store energy and is capable of releasing energy directly to the contactor’s opening coil acts, similar to regular operation. This retrofit is not compatible with the motor-driven actuator, however can be used with feeder breaker protection and in fact operates faster than during regular operation, so only in the case that the ETR does not open would the feeder breaker protection will be triggered. Once the ETR opens the contactor, the turbine will remain in emergency mode until local troubleshooting is completed. According to ABB specifications, the contactor should be replaced every three ETR trips, and the ETR should be replaced if it trips 50 times, however according to AWP, the likelihood of several ETR trips at the same turbine are very low.

AWP have tested the ETR retrofit in a climatic chamber to simulate different environments, as well as at multiple operational projects. Furthermore, the ETR has been validated by both switchgear suppliers (Ormazabal and Iberica), and DNV considers the ETR to be capable of operating reliably, as tests in the field have shown the ETR modules to have operated as expected and opened the contactors when contactor opening failures were detected.

EFA activation: According to AWP, the EFA function in MACR2 electronic boards produced prior to October 2014 had not been enabled in factory, which has been identified as one of the root causes in AWP’s RCA. AWP have since conducted a fleet-wide review of the EFA configuration and undertook a re-work campaign to ensure that this function has been enabled in all MACR2 electronic boards. While EFA activation alone does not mitigate the risk of a stator contactor failure entirely, it does eliminate the risk of this root cause from occurring.

AWP has developed alternative switchgear suppliers: Iberica and Ormazabal switchgear, both with Siemens 3TM contactors, which have been unaffected. Unlike the ABB contactor models, the Siemens contactor needs to be continuously fed power to remain in the closed position, therefore when the power source is removed, it will automatically open, protecting downstream equipment. The Siemens contactor is compatible with switchgears manufactured with ABB contactors (with kit), and as of July 2017, AWP began installing the Siemens 3TM contactor on new wind turbines.

According to AWP, a 12-month trial test using the Siemens contactor has been successfully completed at an operating wind project. DNV has reviewed the final retrofit test summary as of 18 November 2019, and confirms that no issues attributable to re-design were observed. DNV also reviewed the one-line diagram of the new Iberica switchgear with Siemens stator contactor and takes no exception.

DNV considers that all existing operational AW3000 turbines are at medium to high risk of the switchgear stator contactor failure mode until the feeder level protection and/or one of the retrofit options (motor-driven actuator or ETR) are implemented, or ABB contactors are replaced with Siemens contactors. AWP have informed DNV that as of February 2020 all AW3000 turbines with the MACR1 or MACR2 contactor models have at least one form of protection, with the exception of two wind projects in Brazil.

For AW3000 turbines manufactured after July 2017 that include the new Siemens contactor, DNV considers the turbines to have an industry-typical risk level that stator contactor failures will occur.

4.6.2.11 Water damage to tower base components during construction

DNV is aware of water damage occurring on components in the tower base during turbine erection, when down tower components and tower sections are installed without a nacelle for a prolonged period of time, allowing rain to affect components. Ineffective or non-existent tower covers were installed on these partially erected towers. AWP has designed a tower cover to prevent water damage. If the Project's construction schedule requires the erection of a tower multiple days or weeks before the nacelle is installed, DNV recommends that an appropriately-designed tower cover be installed. DNV notes that on any given project, the responsibility of such tower covers may fall on the project itself, the BOP contractor, or AWP; DNV recommends that this responsibility be made very clear to avoid potential issues.

4.6.2.12 INDAR generator stator failures

DNV is aware of generator failures occurring as a result of stator cable degradation on INDAR TAR630XA6N60N and TAR630XA6B60N models. AWP has communicated to DNV that a complete degradation of the stator cable semiconductor layer has been observed in failed cables, without which the electrical field distribution inside the cable cannot be controlled, causing accelerated ageing of the insulation and subsequent failure. As of February 2020, 48 generators have been affected in ten different wind projects with 60 Hz generators, with all but one of the generators produced in one factory within a certain time period up to December 2016.

AWP initiated its 8D RCA process in June 2018 and has identified several contributing factors which may result in stator cable degradation, including:

- Cable selection resulting in marginal safety factors;
- Cable layout causing high electric field concentration; and
- Grid quality resulting in overvoltage events during synchronization and disconnection, and in some cases harmonics in voltage wave form.

Earlier in 2019 at AWP's request, DNV Energy Spain conducted an RCA regarding the issue and found cable selection and cable layout to be the root causes for this failure. Since these root causes were identified, AWP has replaced original stator cables in potentially affected high-risk turbines with new ones that have greater cross-sectional area (35 mm^2 instead of the original 25 mm^2) and improved cable layout. AWP claims that the new cable routing and size significantly increase stator cable safety margins. These design modifications have also been applied to the second version of the generator models, which have no reported failures as of February 2020.

As a containment effort, AWP issued TILs to potentially affected windfarms to inspect stator cables if related alarms appeared. If stator cable degradation is identified prior to generator failure via related alarms, repairs can be performed uptower. Crews are available in the United States to perform the work, and it is expected to take between one and 1.5 days to complete. AWP has reported that repaired generators have not required subsequent repair.

DNV considers that AWP has been proactive in their actions to contain and remedy this issue, and that the root causes have correctly been identified. However, no cable replacements have been undertaken for generators produced at INDAR's second factory in Beasain. Until AWP confirms cable replacement and rerouting has been completed on all potentially affected generators, DNV considers there to be a low risk of generator failure as a result of this issue; this risk is only for generators produced prior to the improved cable layout and increased cable cross-sectional area. However, through proper monitoring and repair, generator failure due to stator cable degradation could be avoided entirely once cable upgrades and rerouting are completed.

DNV recommends that any project with INDAR TAR630XA6N60N and TAR630XA6B60N generator models (produced in Segorbe or Beasain) ensure that TILs SER_TEC_00_00330-00 and IMTO0218 are implemented in order to avoid generator failure and replacement.

4.6.2.13 Gearbox pinion cracks

DNV is aware of high-speed stage failures on Moventas gearboxes used in AW3000 turbines, due to pinion cracks and subsequent teeth damage in the high-speed shaft (HSS) and low-speed shaft (LSS) gear parts of the gearbox helical stage. Moventas gearboxes represent approximately 90% of the AW3000 gearbox fleet, and as of June 2019, 21 gearboxes (both PPLH-2900.1 and PPLH-2900.2 models) have been affected by this issue.

Cracks have been observed to form on the pinion gear and propagate for up to three to four weeks following the initial crack initiation, until there are breaks in the gear teeth. According to AWP, gearboxes can continue to operate even with a broken tooth under modified operation until repairs can be made. Considering the type of gear teeth failure, DNV agrees that it is likely possible to continue to operate the turbine, although the repairs should be scheduled and performed rapidly. These repairs can take one to two days to complete and are completed uptower by Moventas technicians, where the HSS or LSS are replaced, depending on which was affected.

AWP is working closely with Moventas who are conducting an RCA, and AWP believes that multiple factors contribute to result in pinion cracks, as metallurgical test results identified no significant non-conformances. As this issue is affecting the second version of this gearbox model (PPLH-2900.2), AWP is also conducting their own RCA. The main factors being considered are material performance, heat treatment and component manufacturing. Moventas are implementing new quality methods to measure 100% of grain size after heat treatment, increase stringency of material purchasing specifications and review working allowances in manufacturing standards.

DNV requests both AWP's and Moventas' RCA associated with gearbox pinion cracks and teeth breakage, when available.

Until more information is gained from the ongoing RCAs, DNV considers there to be a low to moderate risk that Moventas gearboxes used in AW3000 turbines could develop pinion cracks and teeth breakage, resulting in ceased or modified operation until repairs are made. Preventative measures that can be taken to identify early failures include regular visual inspection of the gears, and carefully reviewing CMS data. DNV recommends that new Projects using Moventas gearboxes elect to include CMS as a Project option, and existing Project's without CMS to evaluate the possibility of installing a CMS, or minimally to regularly inspect gear teeth for cracks and/or breakage.

4.6.2.14 Leading edge blade cracks

DNV is aware of cracks having formed on some AW61.2 blades (for the AW125 turbine). The cause of the cracking may also affect the AW64.7 and AW68.7 blades on the AW132 and AW140 turbine models, respectively.

In the AW61.2 blade, the cracks are located at the leading edge (LE) of the blade at Z7, Z10, and Z13, where the notation "Zx" refers to spanwise position, measured from the blade root face and "x" is distance in meters. The crack locations coincide with joints between the LE mold flange tools used during blade manufacturing. DNV understands that the same mold flange tools are used in manufacture of the AW64.7 and AW68.7 blades as well.

During a blade factory manufacturing evaluation carried out by DNV in August 2020 at the Matamoros blade factory, DNV observed spanwise offsets, or steps, between adjacent LE mold flange tools at 6 and 11.5 m from the root on one of the AW68.7 blade molds. The offsets are estimated to be approximately 5 to 6 mm. These offsets were observed to cause significant wrinkles in the LE flange laminate. A wrinkle in laminate weakens the structure, potentially leading to initiation of damage such as the cracking observed in some AW61.2 blades.

AWP started a root cause analysis (RCA) for this problem using their 8D process. Until AWP provides well-supported information indicating otherwise, DNV considers all AW blades manufactured at the Indutch, Lumbier, and Matamoros facilities to be at risk of LE cracking due to the wrinkle flaw. Unless remediated, in DNV's opinion cracking is likely to progress and may result in a catastrophic blade failure. DNV considers all AW blades manufactured at these locations to be in the at-risk population, until demonstrated otherwise.

The problem is likely mold and time specific, and thus it may affect certain blade serial numbers and not others. Mold flanges may have been aligned in early production, and developed gaps/offsets over time due to use and lack of proper maintenance. If AWP performed maintenance and realigned the mold sections, then blades produced after a certain date might not have the wrinkle manufactured into the LE flange. Further, the mold flange condition may vary from mold to mold. Therefore, it is possible that not all blades at a given project will be affected by this issue, depending on the mold condition at the time of blade manufacture.

For new and operating projects, DNV recommends internally inspecting 100% of the Project blades for this flaw and associated damage (if operational), and every six months thereafter, with adjustment to the interval based on findings (e.g. risk-based inspections). These inspections should be performed in coordination with AWP.

Should inspection results indicate that repairs are required, Nordex has developed repair instructions and DNV recommends that repairs are executed. DNV has reviewed the repair instructions and provided feedback to Nordex; DNV understands that the most recent revision of the repair instructions include DNV's feedback..

DNV recommends that an appropriate budget be put in place to account for inspections, repairs, and downtime associated with this issue. Based on the information known to DNV at this time, in DNV's opinion there is a higher risk of a wrinkle defect in the leading edge structure of all AW blades manufactured at Indutch, Lumbier, and Matamoros facilities than is typical in the industry. However, as noted above, the possibility exists that further information from AWP and/or blade inspection results could indicate otherwise. DNV may alter the risk level and associated recommendations presented here should additional information be provided.

4.6.2.15 Blade strikes

DNV is aware of incidents of blade strikes (blade striking tower) on the AW3000 platform that have occurred globally over the past few years. Limited information has been provided to DNV at this time, however AWP has indicated that these failures are un-related to the known technical issues presented herein. ***DNV requests more information from AWP on the five AW3000 blade strikes that have occurred globally over the past few years.***

4.6.3 Historical performance and availability

DNV has performed a fleet availability audit for the AW125/3000 in July-August 2017. The fleet considered included more than 100 turbine-years of operation, covered the period from May 2016 to April 2017, had an appropriate SCADA data coverage above 99%, and resulted in a DNV calculated wind-in-limits turbine availability of 96.9%, thus exceeding DNV's requirement of 95%.

It is of note that Acciona has also shared Acciona's calculated availability at various projects, including both AW116 and AW125 turbines, and confirmed that in general, the AW125 turbines are operating at slightly better availability levels than their AW116 predecessors. DNV considers this to be typical, as generally in the wind industry, early-model years of a given platform tends to have slightly more teething issues, while more recent model-year turbines benefit from lessons-learned and generally achieve improved availability levels.

4.7 DNV Opinion: design status and projected availability

DNV considers a turbine to be *commercially proven* [28] in a given region (such as North America or Europe) when the following criteria have been demonstrated in that region:

1. *Viable Company:* Capable of performing all contractual and commercial obligations;
2. *Service & Technical Infrastructure:* Can demonstrate the ability to support warranty, O&M, and supply chain obligations in the region;
3. *Certified Design:* The region's version has a Design Statement of Compliance to IEC 61400-1 from an accredited certification agency;
4. *Track Record:* There are at least 100 turbine-years of experience in the region's market, and the region's fleet has operated at ⩾95% fleet-wide average turbine availability for a full year.

For the purposes of this review, the region under consideration is North America, specifically Canada and the U.S.

AWP has well-established engineering, manufacturing, and field service capabilities. Based on DNV's knowledge of AWP, as well as AWP's track record in North America with the AW1500 turbine platform, DNV considers that the first two criteria above are met in North America. Additionally, multiple variants within the AW3000 platform have obtained a type certificate; a type certificate requires both a design statement of compliance, as well as additional testing, e.g. blade fatigue testing, and manufacturing quality review, and as such, the third criterion above is considered to be fully achieved.

With regard to the fourth criterion, as detailed above, DNV has performed a fleet availability audit for the AW125/3000, which resulted in a DNV calculated wind-in-limits turbine availability of 96.9%, thus exceeding DNV's requirement of 95%. As such, the AW125 turbine meets the fourth criterion.

That being said, in parallel to performing this availability audit, DNV has been made aware of issues occurring in the AW3000 fleet (in particular blade delamination and web separation, and to a lesser extent blade stud failures, as described in this report). These issues have first occurred in June-July 2017 and as such, are subsequent to the data sample period reviewed by DNV and therefore not captured in the availability figure presented above. As of May 2020, AWP has completed a full-scale blade test on an

AW61.2 blade to assess the effects of delamination and cavities (and associated cracks) on the full structural capability of the blade. The blade successfully completed testing, showing that the tested blade is capable of withstanding 20-year design loads, with delamination and proposed shear clip retrofit to contain web separation. While DNV acknowledges successful blade testing to be a positive indicator, some variability exists in the manufacturing and site-specific wind conditions. As such, DNV considers AW56.7 and AW61.2 blades exhibiting delamination to have industry typical risk, and blades with shear clips to prevent web separation to also have industry typical risk, assuming that internal risk-based inspections are implemented. AWP's blade stud failure RCA is well advanced and AWP has reported promising corrective actions. DNV advises that the availability figures as reviewed by DNV and presented above may not be representative of future AW125 availability. Consequently, DNV does not currently consider the AW125/3000 turbine, or other turbines in the platform, to be proven.

Before reaching the commercially proven status but after a period of experience, a turbine model may go through a period of being considered a *qualified* design[6]. DNV uses the degree to which a turbine is commercially proven or qualified in determining its default ramp-up and long-term availability. The *qualified* classification recognizes the demonstrated capabilities of a turbine's predecessors and/or demonstrated performance in other markets, and indicates that DNV considers the turbine to be moving towards becoming commercially proven.

With over 2,491 worldwide installations as of 14 January 2021, and based on the availability data reviewed and AWP's demonstrated experience with operations of turbines in North America (based on the AW1500 fleet of turbines), DNV considers the AW100/3000, AW109/3000, AW116, AW125 and AW132 turbines to be qualified in North America.

DNV may also consider these turbines to be qualified in other regions or countries where AWP has well-established and demonstrated O&M and service capabilities. Status for other countries or regions may be reviewed by DNV on a project-specific basis.

Based on the significantly larger rotor size, DNV considers the AW140/3000 turbines to be different from the other AW3000 turbines and thus considers it separately.

DNV recommends assuming a one-year ramp-up in availability after commissioning, with nominal technical turbine availability of 96.0% being achieved for the AW125 and AW132 turbines, and of 95.5% for the AW140 once the typical construction and initial operation teething issues have been overcome, assuming good operations and maintenance practice. The nominal availability represents the expected average availability in project years two to ten, with declining levels expected in subsequent years.

It should be noted that there are many variables that contribute to turbine availability, and the turbine is but one of them. Variables associated with the site and owner, such as availability of spare parts, O&M organization, manufacturer service infrastructure, and site location/conditions also play significant roles. Therefore, this generic turbine availability projection carries with it some level of uncertainty and should be re-examined in a project-specific context.

6 See DNV's position paper on turbine reliability for types of experience needed to reach "qualified" status and for more discussion of this subject [28].

4.8 Expected operating life

The typical design operating life of a wind turbine is 20 years, as required in the IEC 61400-1 design standard. Based on the type certification obtained for multiple variants, DNV expects that given proper operating conditions, the AW3000 turbines will achieve a 20-year operating life.

5 SUMMARY AND CONCLUSIONS

On the basis of the investigation the following summaries and conclusions can be made:

- Formerly part of Acciona S.A., Acciona Wind Power (or AWP, manufacturer of the Acciona turbines) merged with Nordex WindPower in April 2016, and now operates as one manufacturer under the name Nordex Group.
- As a turbine manufacturer, Nordex Group has significant turbine installation experience in multiple countries including Europe, Latin America, China, Australia, U.S., and Canada.
- Acciona Energy, a subsidiary of Acciona S.A., is one of the largest owners and operators of wind turbines in the world, operating not only AWP wind turbines but also multiple other turbine types. AWP advised that this experience has been used in the design of the AW1500 platform, and later in the design of the AW3000 platform.
- In-house manufacturing consists of blades (56.7 m, 61.2 m, 64.7 m and 68.7 m through Acciona Blades) and concrete towers, and assembly is performed for nacelles and hubs. Blades may also be supplied built-to-print by TPI in China, Aeris in Brazil, Indutch in India and TMT in China. AWP subcontracts all other manufacturing.
- The AW3000 turbine design is relatively conventional, with the exception of the 12 kV generator, which AWP has previously used successfully in its AW1500 platform. The AW3000 turbines are variable-pitch machines that use a DFIG generator with a converter to operate at variable speed. Various hub heights are available, ranging from 84 m on steel tower to 137.5 m on concrete tower.
- Multiple variants of the AW3000 platform have obtained type certification, including some cold weather package variants.
- Based on the significantly larger rotor size and doubled power rating, DNV considers the AW3000 turbines to be sufficiently different from the AW1500 turbines that its design and availability projection should be considered separately, although AWP's experience with the AW1500 in specific markets, particularly North America and Spain, has demonstrated AWP's capabilities in terms of O&M and support to the deployment of its turbines.
- The design and development of the AW3000 turbine platform dates back to 2006, with first prototype installation in 2008: DNV sees the significant experience gained with this prototype as beneficial.
- The AW3000 platform has been introduced commercially to the market in 2012 and has a significant track record, with over 2,491 turbines installed as of 14 January 2021. The platform has seen a significant number of installations in 2014 through 2020.
- DNV has performed a fleet availability audit for the AW125/3000 in July-August 2017. The fleet considered included more than 100 turbine-years of operation, and resulted in a DNV calculated wind-in-limits turbine availability of 96.9%, thus exceeding DNV's requirement of 95%.
- While the availability audit shows that the turbine meets DNV's criterion of above 95% availability, DNV has been made aware of issues occurring in the AW3000 fleet that have first occurred in June-

July 2017 and as such, are subsequent to the data sample period reviewed by DNV and therefore not captured in the availability figure presented above.

- With over 2,491 worldwide installations as of 14 January 2021, and based on the availability data reviewed and AWP’s demonstrated experience with operations of turbines in North America (based on the AW1500 fleet of turbines), DNV considers the AW100/3000, AW109/3000, AW116, AW125 and AW132 turbines to be qualified in North America.
- DNV recommends assuming a one year ramp-up in availability after commissioning, with nominal technical turbine availability of 96.0% for the AW125 and AW132 turbines, and of 95.5% for the AW140 being achieved once the typical construction and initial operation teething issues have been overcome, assuming good operations and maintenance practice. The nominal availability represents the expected average availability in project years two to ten, with declining levels expected in subsequent years.

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