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February 3, 2016

Via electronic filing

Daniel P. Wolf
Executive Secretary
Minnesota Public Utilities Commission
121 7th Place East, Suite 350
St. Paul, MN 55101-2147

Re: Compliance Filing and Supplement to the Petition for Modification or Amendment to the Site Permit

In the Matter of Flat Hill Windpark I, LLC's Site Permit for a 201 Megawatt Large Energy Conversion System and Associated Facilities in Clay County, Minnesota
Docket Nos. IP-6687/WS-08-1134 and IP-6687/CN-08-951

Dear Mr. Wolf:

Pursuant to the Minnesota Public Utilities Commission's ("Commission") October 6, 2015 *Order Postponing Decision on Permit Amendment and Requiring Filings* (the "Order"), Flat Hill Windpark I, LLC ("Flat Hill") is filing the attached compliance filing to provide the Commission with the updated Project information requested by the Commission in the Order. Additionally, because this updated Project information is different from the information contained in the Site Permit, Flat Hill is also requesting additional amendments to the Site Permit consistent with this updated information.

Thank you for your attention to this matter.

Sincerely,

STINSON LEONARD STREET LLP

/s/ Andrew J. Gibbons

Andrew J. Gibbons

AJG:cmw
Attachments

STATE OF MINNESOTA
BEFORE THE
MINNESOTA PUBLIC UTILITIES COMMISSION

In the Matter of Flatt Hill Windpark I, LLC's Site Permit for a 201 Megawatt Large Energy Conversion System and Associated Facilities in Clay County, Minnesota	**))))))**	**Docket Nos. IP-6687/WS-08-1134 IP-6687/CN-08-951**

COMPLIANCE FILING AND SUPPLEMENT TO PETITION FOR MODIFICATION OR AMENDMENT TO THE SITE PERMIT

Pursuant to the October 6, 2015 *Order Postponing Decision on Permit Amendment and Requiring Filings* (the "October 6, 2015 Order") of the Minnesota Public Utilities Commission ("Commission"), and pursuant to Minn. Stat. § 216F.04(d) and Minn. R. 7854.1300, subp. 2., Flat Hill Windpark I, LLC ("Flat Hill") hereby submits filing and enclosed information in compliance with the Order, and further requests additional modifications or amendments of the site permit ("Site Permit") in the above-referenced docket.

INTRODUCTION

On February 5, 2010, the Commission issued a Site Permit to Flat Hill (formerly Noble Flat Hill I, LLC) for a 201 MW large wind energy conversion system project ("Project") in Clay County, Minnesota.

The site permit required Flat Hill to either obtain a power purchase agreement or other legally enforceable mechanism for selling the project's electricity within two years of the date the Site Permit was issued or advise the Commission of the reason for failing to do so. The permit imposed the same requirement for beginning construction of the Project.

On May 20, 2011, the Commission extended the deadlines for obtaining a power purchase agreement and beginning construction to two years from the date of the order. [1] On August 27, 2013, the Commission issued an amended site permit further extending the deadlines to two years from the date of the amendment.[2]

On July 15, 2015, Flat Hill submitted a Petition for Modification or Amendment to the Site Permit, in which Flat Hill requested the Commission to amend the Site Permit to extend by two years the deadlines for obtaining a power purchase agreement, completing preconstruction surveys, and beginning construction.

In response to Flat Hill's July 15, 2015 amendment petition, the Commission issued the October 6, 2015 Order in which the Commission postponed its decision on Flat Hill's amendment petition, and required Flat Hill to do the following within 120 days:

1. Request a Natural Heritage Inventory System ("NHIS") review within 20 days of the October 6, 2015 Order and provide the results to the Commission within 20 days of receipt of the information from the Minnesota Department of Natural Resources, including a report detailing any changes from the original NHIS review;
2. Provide information on any avian and bat studies performed since the last extension;
3. Provide information on anticipated turbine design; and
4. Provide updated preliminary turbine layout and associated environmental information based on the most current data available.

In a compliance filing on October 26, 2015, Flat Hill notified the Commission of its request for an updated NHIS review for the Project, and, within 20 days of receipt of the updated NHIS review

[1] Order Dismissing Contested Case Proceedings and Adopting and Modifying Proposed Order issued May 20, 2011.

[2] Order Granting Amendments to Site and Route Permits and Required Compliance Filings issued August 27, 2013.

results, provided the results of the updated NHIS review, including a report detailing changes from the original NHIS review, in a compliance filing dated December 30, 2015.

Flat Hill respectfully submits this compliance filing to address the remaining compliance requirements of the Commission's October 6, 2015 Order (items 2 through 4 above), and respectfully requests further amendments to the Site Permit to update the Site Permit consistent with the updated information included with this filing.

I. COMPLIANCE FILING INFORMATION

As noted in the Introduction above, the Commission requested updated Project information related to NHIS data, avian and bat studies performed, anticipated turbine design, and updated preliminary turbine layout information. Flat Hill has already filed with the Commission the updated NHIS data. This section details information regarding the remaining areas.

A. Avian and Bat Information

Flat Hill continues to work to develop additional information regarding potential impacts to avian and bat species in the Project area. As Flat Hill noted in its August 17, 2015 Reply Comments, Flat Hill has engaged its consultant Tetra Tech to complete updated Spring and Fall avian surveys for the Project site in 2016.[3] A summary of the proposed survey activities provided by Tetra Tech is included as Exhibit A to this filing. Survey protocol will be consistent with the original surveys conducted in Spring and Fall of 2008. Flat Hill will provide the final results of the surveys to the Commission within 4 weeks of completion of final survey efforts for each season. Using the information obtained from these surveys, Flat Hill will coordinate with DNR and the Department to prepare and finalize an Avian and Bat Protection Plan prior to construction consistent with the requirements of the current Site Permit, including establishing the appropriate post-construction

[3] A Fall 2015 avian survey could not be completed following the Commission's October 6, 2015 Order because the Fall survey season had already passed.

monitoring to be completed. In the event the survey results raise concerns about the potential for avian and bat impacts, the Commission can address such issues as they arise.

B. Anticipated Turbine Design

In its initial application for a permit, Flat Hill specified that the turbine designated for the Project was the 1.5 MW General Electric (GE) SLE wind turbine. The 1.5 MW GE SLE turbine had a rotor diameter of 77 meters (253 feet), and a hub height of 80 meters (about 262 feet). Wind turbine technologies have continued to evolve and improve, and Flat Hill has now identified a different wind turbine generator for the Project.

Flat Hill has identified the Acciona AW 132/3000 wind turbine as the likely turbine for the Project.[4] The Acciona AW 3000 is a line of 3.0 MW turbines with rotor diameters ranging from 100 m to 132 m (328 ft to 433 ft) and hub heights ranging from 84 m to 137.5 m (276 ft to 451 ft) to cater to different wind classifications. For the Project, taking into consideration site-specific factors, Flat Hill anticipates utilizing the AW 132/3000, which has a rotor diameter of 132 m (433 ft), and towers with a hub height of 84 m (276 ft).[5] The specifications of the Acciona AW 132/3000 are provided in Table 1 below for comparison to the 1.5 MW GE SLE turbine. Additional turbine information and specifications are provided in Exhibit B. The Acciona AW 132/3000 turbine will provide significant improvements in turbine performance, and, as is described in the next section, will enable modifications to the Project layout that will substantially reduce the potential for impacts from the Project layout.

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[4] Flat Hill does not have a turbine supply agreement in place at this time, and does not anticipate executing a turbine supply agreement until an offtake arrangement is executed for the Project. Thus, Flat Hill may commit to a different turbine at a later date based on market conditions and Project-specific factors. Any turbine used, however, is likely to have specifications similar to those of the Acciona AW3000. Thus, the turbine design and associated layout information provided in this filing, although not final, portray a more accurate picture of the Project as envisioned at this time than the turbine design and layout provided to date. If the turbine selection and/or layout change at a subsequent date, Flat Hill will seek any resulting Site Permit amendments in a subsequent filing as required by the Site Permit and Commission rules.

[5] As is shown in the turbine specifications provided in Exhibit B, 120 m (394 ft) towers can also be used for this model.

Table 1: Wind Turbine Specifications

Characteristic	1.5 MW GE SLE Turbine	Acciona AW 132/3000
Nameplate Capacity	1,500 kW	3,000 kW
Hub Height	80 m (262 ft)	84 m (276 ft)
Rotor Diameter	77 m (253 ft)	132 m (433 ft)
Total Height[1]	119 m (389 ft)	148.7 m (488 ft)
Cut-in wind speed[2]	3.5 m/s (7.8 mph)	3 m/s (6.7 mph)
Rated capacity wind speed	14.5 m/s (55.9 mph)	10 m/s (22.4 mph)
Cut-out wind speed	25 m/s (55.9 mph)	25 m/s (55.9 mph)
Maximum sustained wind speed[3]	55 m/s (123 mph)	52.5 m/s (117.4 mph)
Rotor Speed	10 to 20 rpm	6.6 rpm to 12.5 rpm
Distance to 50 dBA noise level for a single wind turbine	650 to 700 ft	*Not Available At This Time*[4]

[1] Total height = the total turbine height from the ground to the tip of the blade in an upright position.
[2] Cut-in wind speed = wind speed at which turbine begins operation.
[3] Rated capacity wind speed = wind speed at which turbine reaches its rated capacity.
[4] Cut-out wind speed = wind speed above which turbine shuts down operation.
[5] Maximum sustained wind speed = wind speed up to which turbine is designed to withstand.
[6] This particular noise metric was provided for the 1.5 MW GE SLE turbine, but is not available for the Acciona AW 132/3000 turbine. As noted below, Flat Hill is working to develop an updated noise model for the Project using the Acciona AW 132/3000 turbine. Additional information regarding the noise specifications of the Acciona AW 132/3000 turbine are provided in Exhibit B.

C. Project Layout

With the selection of the Acciona AW 132/3000 turbine, Flat Hill has also developed a new layout for the Project based on the new turbine. A preliminary revised layout is provided in Exhibit C to this filing, which reflects a conservative Project layout. Use of the Acciona AW 132/3000 turbine offers a number of advantages for the Project, each of which is illustrated in the revised layout:

- The larger turbine capacity allows for the total number of turbines in the Project to be reduced from 134 to 67 turbines;
- The overall footprint of the Project can be reduced, including avoidance of areas where radio interference could be an issue;
- The efficiency of the overall layout is improved by removing rows where efficiency was reduced because of downstream wake effects; and
- The spacing in between turbines is increased in accordance with Site Permit spacing requirements because of the larger rotor diameter of the Acciona turbine.

The revised layout is designed to comply with all setback requirements, and Flat Hill anticipates that the reductions in the number of turbines and overall footprint will result in reduced potential for Project impacts. Flat Hill continues to work to refine the revised layout and further reduce potential impacts. Flat Hill has engaged Tetra Tech to develop more detailed constraint maps for the revised layout, and to develop sound and shadow flicker modeling reports for the Project. Flat Hill will commit to completing and submitting the detailed constraint maps and the noise and shadow flicker modeling reports to the Commission within 120 days of the extension of the Site Permit. While Flat Hill does not have noise and shadow flicker modeling completed at this time, Flat Hill will still be required to comply with all Site Permit requirements and applicable law and regulations in the final siting of turbines, including Minnesota Pollution Control Agency noise standard compliance and post-construction noise monitoring, and pre-construction shadow flicker data for each residence subject to exposure from turbine shadow flicker. Additionally, Flat Hill plans to evaluate the revised turbine locations for potential impacts to cultural resources, wetlands, and other biological and natural resources in compliance with Site Permit pre-construction evaluation requirements.

II. SUPPLEMENTAL SITE PERMIT AMENDMENTS

Because Flat Hill has identified a new turbine design and layout for the Project, certain information contained in the Site Permit requires updating to reflect these changes. Flat Hill respectfully requests that the Commission make corresponding amendments to the Site Permit so that any amended Site Permit issued by the Commission includes the most current turbine and layout information for the Project. These proposed amendments are in addition to the amendments requested in Flat Hill's July 15, 2015 petition to the Commission.

Specifically, Flat Hill requests the following amendments to the Site Permit to update turbine design information consistent with the selection of the Acciona turbine described in Section I.B. above:

SECTION 1. PROJECT DESCRIPTION

The up to 201 MW LWECS authorized to be constructed in this Permit will be owned and operated by Flat Hill Windpark I, LLC. The Project will consist of ~~134~~ 67 wind turbine generators each ~~1.5 MW~~ 3.0 MW in capacity with a combined nominal nameplate capacity of no more than 201 MW. . . .

4.9 WIND TURBINE TOWERS

Structures for wind turbines shall be self-supporting tubular towers. The towers will be up to ~~328 feet~~ 120 meters above grade measured to hub height.

Amending these provisions will update the Site Permit to reflect the most current wind turbine information for the Project, but will not otherwise change the terms and conditions of the Site Permit, including the provisions establishing setback, layout, survey, and/or reporting requirements. The Flat Hill Project still must comply with all Site Permit terms and conditions. Furthermore, the Project continues to be located entirely within the footprint originally evaluated by the Commission (including with adjustments to address potential issues with radio interference by the Project). Finally, the Project will not prejudice the pre-construction evaluation process outline by the Commission, as it will continue to be subject to the pre-construction reporting, survey, and administrative compliance obligations set forth in the Site Permit.

Accordingly, the additional amendments identified in this filing will not substantively change the Commission's finding in its original approval of the Site Permit or whether the Project is compatible with environmental preservation, sustainable development, and the efficient use of resources, and it is appropriate, and consistent with Commission precedent,[6] for the Commission to grant these additional amendments.

[6] *See, e.g.*, *In the Matter of the Application of Pleasant Valley Wind LLC for a Site Permit for the 301 MW Pleasant Valley Project in Dodge and Mower Counties,* Order Amending Site Permit, MPUC Docket No. IP-6828/WS-09-1197 (Feb. 10, 2014) (approving modifications to the site permit to reflect a new turbine type); *In the Matter of Lake Country Wind Energy, LLC's Application for a 41-Megawatt Large Wind Energy Conversion System in Kandiyohi and Meeker Counties,* Order Amending Site Permit, MPUC Docket No. IP-6846/WS-10-798 (June 3, 2013) (approving amendments to site permit including changing the turbine type and layout for the project due to changes in turbine technology and availability); *In the Matter of the Site Permit Issued to Kenyon*

III. CONCLUSION

Because Flat Hill has complied with the Commission's requests to update Project information, Flat Hill respectfully requests that the Commission find good cause to, and grant Flat Hill's request for a modification of the Site Permit to (a) extend the time to obtain a PPA or other enforceable mechanism for the sale of power from the Project, (b) extend the time to commence construction of the Project; (c) extend the expiration date of Flat Hill's Site Permit, and (d) modify Section 1, Section 4.9, and Attachment 1 of the Site Permit to reflect the new wind turbine generator and associated layout. Flat Hill further continues to support the additional conditions of such a grant of the requested amendments to the Site Permit as set forth in the Commission's October 6, 2015 Order, and would also support additional conditions related to providing updated avian and bat survey results and noise and shadow flicker modeling results.

Dated: February 3, 2016

Respectfully submitted,

/s/ Andrew J. Gibbons
Andrew J. Gibbons
Brian M. Meloy
STINSON LEONARD STREET
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Minneapolis, Minnesota 55402
Telephone: (612) 335-1500
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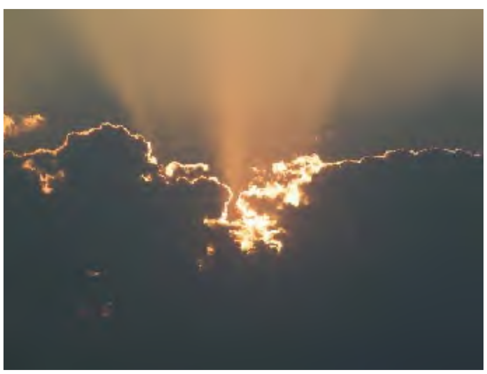
Wind, LLC for a Large Wind Energy Conversion System in Goodhue County, Order Amending Site Permit, MPUC Docket No. IP-6605/WS-06-1445 (February 18, 2009) (approving amendments to site permit including changes to the turbine type and turbine spacing due to concerns with the reliability of the originally-designated turbine).

<u>EXHIBIT A</u>

<u>AVIAN AND BAT SURVEY PROPOSAL FROM TETRA TECH</u>

TETRA TECH

Proposal for Avian Point Count Surveys
Flat Hill Windpark I
Clay County, Minnesota
February 2, 2016



Suriyun Sukduang
Vice President, Engineering and Project Development
Quantum Utility Generation

February 2, 2016

Suriyun Sukduang, Vice President, Engineering and Project Development
Quantum Utility Generation
1401 McKinney Street, Suite 1800
Houston, TX 77010
Sent via email: SSukduang@quantumug.com

Subject: **Proposal for Avian Point Count Surveys**
Flat Hill Windpark I Project
Moland and Spring Prairie Townships, Clay County, Minnesota

Dear Mr. Suri Sukduang:

Tetra Tech is pleased to provide this proposal to conduct avian point count surveys for the proposed Flat Hill Windpark I Project in Moland and Spring Prairie Townships, Clay County, Minnesota. Tetra Tech understands that a new project layout is pending.

With extensive experience in providing site assessment and survey programs for wind energy facilities, we are confident in our ability to assist Flat Hill Windpark I, LLC through this phase of the project.

Please feel free to contact me at (612) 643-2224 or kim.gorman@tetratech.com if you have any questions regarding this submittal.

Sincerely,

Kimberely Gorman, GISP
Senior Program Manager

CONTENTS

1.0 SCOPE OF WORK

Tetra Tech's proposed scope of work for the Flat Hill Windpark I (the Project) includes the following task:

- Task 1 – Avian Point Count Surveys - 2016

The task is described below. Details regarding costs, scheduling, and staffing for this task is provided in subsequent sections of this proposal.

1.1 TASK 1 – AVIAN POINT COUNT SURVEYS

Tetra Tech recommends that avian point count surveys be conducted at the Project to reassess avian use of the Project area since surveys were last conducted in Spring and Fall of 2008. The purpose of the avian surveys is to obtain quantitative documentation of avian species composition and use of the Project area during the spring and fall migration periods in order to assess Project risk to avian species. Tetra Tech's approach to avian surveys will follow the general recommendations from the USFWS Land-based Wind Energy Guidelines. Surveys will be conducted weekly at 8 survey locations within the Project area from March 21, 2016 through June 10, 2016 and August 15, 2016 through November 4, 2016 for a total of 24 survey weeks.

Avian point count surveys will be 20 minutes in duration. The order in which avian observation points are surveyed will be varied so that roughly equal numbers of surveys at each point are conducted during the morning and afternoon. If evident during the field survey, more specific information on habitats, especially areas that appear to be attractive to birds, will be documented.

Each time a bird is detected during the avian point counts, the surveyor will record the species, number of individuals, distance from observer, habitat type, type of detection (visual or auditory), and behavior (flying, perching, walking, etc.). Tetra Tech will contact the Flat Hill Windpark I Project Manager within one business day of any sightings of federally threatened or endangered species or bald or golden eagles at the Project.

Micro siting of the point-count circle plot locations will occur during an initial site visit by a Tetra Tech biologist to ensure that land uses and habitat types are appropriately represented within the survey plots. The first of the 12 proposed weekly fall avian surveys will be conducted during the initial site visit.

Deliverables for this task will include two reports: a spring survey report and a fall survey report. Each report will be completed within five weeks of the completion of the final week of the season's survey efforts.

2.0 ASSUMPTIONS

2.1 GENERAL ASSUMPTIONS

- Tetra Tech assumes that Flat Hill Windpark I, LLC will provide all required detailed facilities layout information and written descriptions of the proposed Project, and that facility maps will be provided in a geo-referenced format compatible with ESRI GIS software.
- Tetra Tech's cost estimate includes overtime and weekend pay for staff in compliance with applicable labor laws and company policies.
- Cost estimates are good for two months following submittal of this proposal.

2.2 ASSUMPTIONS FOR TASK 1 – AVIAN POINT COUNT SURVEYS

- The number of survey locations is subject to change based on habitat coverage, time constraints, and safety considerations. If more than 8 survey locations are required, additional levels of effort and associated costs will be discussed with Flat Hill Windpark I, LLC for approval.
- The results of the spring avian point count survey will be submitted in a single report submitted to Flat Hill Windpark I, LLC within five weeks of the final spring survey date.
- The results of the fall avian point count survey will be submitted in a single report submitted to Flat Hill Windpark I, LLC within five weeks of the final fall survey date.
- The costs associated with this task do not include agency consultation.

3.0 SCHEDULE

3.1 SCHEDULE OF WORK

The table below provides Tetra Tech's anticipated schedule for completion of the scope of work described within this proposal.

Task	Schedule
Authorization to Proceed	February 22, 2016
Spring Survey Field Work Begins	March 21, 2016
Spring Survey Field Work Ends	June 10, 2016
Final Spring Avian Survey Report Complete	July 15, 2016
Fall Survey Field Work Begins	August 15, 2016
Fall Survey Field Work Ends	November 4, 2016
Final Fall Avian Survey Report Complete	December 9, 2016

3.2 PAYMENT SCHEDULE

Tetra Tech anticipates that invoices will be submitted to Flat Hill Windpark I, LLC monthly on a time and materials basis.

4.0 TEAM ORGANIZATION & QUALIFICATIONS

4.1 KEY STAFF

The table below identifies the key personnel that are expected to be involved in support of this scope of work. Additional contact information will be provided upon authorization.

Name	Organization Role
Kimberely Gorman	Tetra Tech – Client Manager
Molly Kuisle	Tetra Tech - Project Manager
Mike Wallgren	Tetra Tech – Environmental Scientist/Avian Biologist

5.0 PRICING

The table below summarizes the proposed time and material not to exceed prices for the scope of work proposed herein. If circumstances arise that prompt additional work that is not included in the current scope, the Project Manager will contact Flat Hill Windpark I, LLC as soon as possible to discuss the possibility of additional work and necessary change orders.

Task	Price
Task 1a – Spring Avian Point Count Surveys – 2016	$[redacted]
Task 1b – Fall Avian Point Count Surveys - 2016	$[redacted]
Total	$[redacted]

TETRA TECH

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2001 Killebrew Drive, Suite 141

Bloomington, MN 55425

EXHIBIT B

ACCIONA AW 132/3000 WIND TURBINE SPECIFICATIONS

DESCRIPCIÓN TÉCNICA AW3000

AW3000 TECHNICAL DESCRIPTION

Rev	*Fecha* *Date*	*Descripción de la revisión* *Description of the revision*
"A"	23.03.06	Elaboración del documento
"K"	02.04.13	Actualizada descripción carcasa de protección nacelle. Nacelle protective cover description updated.
"L"	14.07.14	Actualización general. General review.
"M"	07.08.14	Actualizado tipos de máquina y número de tramos torre acero Types of wind turbines and steel tower section number updated
"N"	25.09.14	Se añade AW132/3000. AW132/3000 added

Realizado / Done	*Revisado / Reviewed*	*Aprobado / Approved*
29-09-2014	29-09-2014	MNP 29-09-2014

1. INTRODUCCIÓN

Este documento resume la descripción técnica de los aerogeneradores AW3000 desarrollados y fabricados por ACCIONA WINDPOWER. A partir de este punto, el texto se referirá genéricamente al aerogenerador AW3000, a no ser que se especifique el modelo concreto.

Las cantidades y tipos de componentes pueden variar en función del modelo de aerogenerador.

1. INTRODUCTION

This document summarizes the technical description of the AW3000 wind turbine platform, developed and manufactured by ACCIONA WINDPOWER. From this point onwards, the text will refer generically to the AW3000 wind turbine, unless specific model variants are discussed.

Quantity and type of components may change depending on wind turbine model.

2. GENERALIDADES

El aerogenerador AW3000 es un aerogenerador de velocidad variable, potencia nominal de 3000kW, tensión nominal de 12kV, y disponible para la generación eléctrica en frecuencias de 50 ó 60Hz.

Existe también un aerogenerador AW3000 para emplazamientos con Bajas Temperaturas, con temperatura ambiente mínima de funcionamiento -30º y temperatura ambiente mínima de supervivencia de -40ºC.

El aerogenerador estará disponible en cinco variantes de rotor, de acuerdo a los requerimientos del proyecto:

2. GENERAL INFORMATION

The AW3000 wind turbine is based on a variable speed design, with 3000kW nominal power, 12kV nominal voltage, and the ability to generate electric power in frequencies of 50 or 60Hz.

An option for a cold weather package is also available for the AW3000, which allows an operating minimum ambient temperature of -30ºC and a survival minimum ambient temperature of -40ºC.

The wind turbine is available in five rotor variants, depending on the requirements for the project site:

- Diámetro 100 metros, clase IEC Ia para emplazamientos con altos vientos.
- Diámetro 109 metros, clase IEC IIa para emplazamientos con medios vientos.
- Diámetro 116 metros, clase IEC IIa para emplazamientos con medios vientos.
- Diámetro 125 metros, clase IEC IIb/IIIa/IIIb para emplazamientos con bajos - medios vientos.
- Diámetro 132 metros, clase IEC IIIb para emplazamientos con bajos - medios vientos.

- 100 m diameter, IEC Class Ia for high wind speed sites.
- 109 m diameter, IEC Class IIa for medium wind speed sites.
- 116 m diameter, IEC Class IIa for medium wind speed sites.
- 125 m diameter, IEC Class IIb/IIIa/IIIb for low to medium wind speed sites.
- 132 m diameter, IEC Class IIIb for low to medium wind speed sites.

El suministro del aerogenerador puede realizarse con diferentes alturas de buje:

The wind turbine can be supplied with different hub heights:

- 87.5 metros (torre acero)
- 92 metros (torre acero)
- 95.5 metros (torre acero)
- 100 metros (torre hormigón)
- 120 metros (torre hormigón)

- 87.5 metres (steel tower)
- 92 metres (steel tower)
- 95.5 metres (steel tower)
- 100 metres (concrete tower)
- 120 metres (concrete tower)

El aerogenerador AW3000 es un aerogenerador de tres palas a barlovento, de eje horizontal. El rotor y la nacelle están montados en lo alto de una torre de

The AW3000 wind turbine is a horizontal axis turbine, with a three bladed rotor placed upwind. The rotor and the nacelle are mounted to a concrete tower hormigón compuesta por cinco o seis tramos, o en torre tubular compuesta por cuatro o cinco tramos de acero.

La máquina emplea un sistema de orientación automática (yaw), que permite un perfecto alineamiento del rotor con la dirección del viento y un enclavamiento estable en la posición óptima de producción, garantizado por su robusto sistema de frenado.

La máquina está provista de un sistema de regulación automática de ángulo de paso (pitch), que permite a cada pala girar, independientemente de las otras dos, sobre su eje longitudinal, comandadas por una misma consigna de posición, a la cual pueden dirigirse las palas con distintas velocidades.

El generador es de tipo asíncrono doblemente alimentado de rotor devanado. Su equipo de potencia permite regular las corrientes rotóricas de manera que la potencia entregada a la red tenga las características de tensión y frecuencia requeridas en cada momento. Con vientos altos, la regulación de potencia al valor nominal se lleva a cabo con el sistema pitch.

composed of five or six sections, or to a tubular tower composed of four or five steel sections.

The turbine uses an automatic system (yaw) that allows perfect alignment of the rotor with the wind direction and a stable interlocking in the optimal production position, supported by a powerful braking system.

The wind turbine is provided with an automatic regulation system controlling the pitch angle. This allows each blade to rotate independently from the other two on its longitudinal axis. They are controlled by the same position set point. The blades can reach this position at different speeds.

The generator is a doubly-fed asynchronous wound-rotor generator. The power converter makes it possible to regulate the rotor currents so that the power transmitted to the grid has the required voltage and frequency characteristics at all times. In high winds, the power is regulated to the nominal value by the pitch system.

3. DESCRIPCIÓN TÉCNICA DEL AEROGENERADOR Y COMPONENTES PRINCIPALES

El diseño del aerogenerador AW3000 consta de un tren de potencia distribuido, constituido por el rotor, el eje lento, la multiplicadora, el acoplamiento elástico y el generador.

El rotor se compone de tres palas sujetas a un buje de fundición, recubierto éste por el cono-nariz, de poliéster reforzado con fibra de vidrio.

El resto de componentes del tren de potencia, salvo el generador, descansan sobre el bastidor delantero, situado ya dentro de la nacelle. El generador descansa sobre el bastidor trasero, también dentro de la nacelle.

Sobre el bastidor delantero se asienta también el grupo hidráulico.

Todos los componentes alojados en la nacelle están protegidos por la carcasa exterior de poliéster reforzado con fibra de vidrio.

La nacelle descansa sobre el rodamiento dentado de yaw, que tiene una pista móvil unida al bastidor delantero y una pista fija

3. TECHNICAL DESCRIPTION OF THE WIND TURBINE AND ITS PRINCIPAL COMPONENTS

The design of the AW3000 wind turbine has a distributed mechanical power transmission. It is comprised of the rotor, the low speed shaft, the gearbox, the flexible coupling and the generator.

The rotor consists of three blades joined to a cast-iron hub, covered by a nose cone of fibreglass-reinforced polyester.

The remaining mechanical power transmission components, except the generator, are secured on the main frame, located inside the nacelle. The generator lies on the generator frame, also inside the nacelle.

The hydraulic unit is also joined to the main frame.

The nacelle cover, made of fibreglass-reinforced polyester, protects all the parts inside in the nacelle.

The nacelle rests on a geared yaw bearing that has a moveable ring bolted to the main frame and a fixed ring to the unida a la torre. La actuación de motorreductoras, instaladas en el bastidor delantero, sobre el rodamiento posibilita la orientación del aerogenerador (yaw).

tower. The yaw gears installed in the main frame, on the bearing, change the direction of the wind turbine (yaw).

La torre de la turbina es la encargada de situar la nacelle a una altura determinada.

The turbine tower is responsible for positioning the nacelle at a given height.

A continuación se detallan las características de los componentes principales.

The characteristics of the main components are provided below.

3.1. Cimentación

3.1 Foundation

Torre hormigón:

La torre es una estructura con elementos prefabricados de hormigón llamados dovelas. La unión de la torre al terreno se realiza mediante la introducción de las barras que sobresalen de las dovelas del tramo inferior en las vainas embebidas en la zapata de hormigón. Posteriormente, se procederá al rellenado de las vainas, y a la realización del anillo de cimentación, ambos con mortero de alta resistencia. La torre entera es postensada, desde la parte superior hasta la cimentación.

Concrete tower:

The tower is a structure with prefabricated concrete elements called keystones. The union of the tower to the ground is made by inserting the steel bars of the lower section keystones into the sheaths embedded in the foundation. Then, the sheaths are filled with high resistance mortar to form a union with the foundation. The entire tower is also post-tensioned from the top of the tower to the foundation.

Torre de acero:

La fijación de la torre al terreno se realiza mediante una corona formada

Steel tower:

The tower is fixed to the ground by a concentric double ring of studs, por una doble hilera concéntrica de pernos, embebida en una zapata de hormigón armado. La parte superior de dichas hileras de pernos verticales queda visible tras el fraguado del hormigón y preparada para recibir el tramo inferior de torre que, posteriormente, una vez que ha sido correctamente asentado, se atornilla a dichas hileras. El diámetro exterior en base de torre de acero es 4600mm.

Las dimensiones, armadura, etc. de la zapata de hormigón depende del tipo de turbina y de las características geológicas del terreno.

3.2. Torre

El aerogenerador es situado en una altura determinada por la torre. Existen cuatro variantes dependiendo del diámetro del rotor:

- 87.5 metros: AW125/3000
- 92 metros: AW116/3000
- 95.5 metros: AW109/3000
- 100 metros: AW100/3000, AW109/3000, AW116/3000, AW125/3000
- 120 metros: AW116/3000, AW125/3000, AW132/3000

embedded in a base of reinforced concrete. The upper part of these rings of vertical studs remains visible after the concrete sets, prepared to receive the tower lower section that, once properly settled, is secured to these studs. The external diameter of the steel tower base is 4600mm.

The dimensions, reinforcements, etc. of the foundation depend on the type of turbine and the geological characteristics of the project site.

3.2. Tower

The wind turbine is positioned at a given height by the tower. There are four different options corresponding to different size rotors:

- 87.5 metres: AW125/3000
- 92 metres: AW116/3000
- 95.5 metres: AW109/3000
- 100 metres: AW100/3000, AW109/3000, AW116/3000, AW125/3000
- 120 metres: AW116/3000, AW125/3000, AW132/3000

Torre hormigón:

La torre se compone de cinco o seis tramos unidos entre sí. Cada tramo está compuesto por dovelas unidas, perfectamente selladas con mortero de alta resistencia a través de sus juntas verticales. La unión entre tramos se realiza introduciendo las barras de acero del tramo superior en las vainas del inferior y el posterior sellado mediante mortero de alta resistencia de la junta horizontal.

Concrete tower:

The tower is composed of five or six sections joined to each other. The sections are composed of joined keystones, with the vertical joints filled with high resistance mortar. The sections are joined to each other by inserting the steel bars of the upper section into the sheaths of the lower section and the horizontal joint filled with high resistance mortar.

Torre de acero:

La torre de acero es una estructura troncocónica tubular y se compone de cuatro o cinco tramos. Dichos tramos se atornillan entre sí por las bridas situadas en sus extremos para formar conjuntamente la torre. La brida inferior del primer tramo se atornilla a la hilera de pernos de la cimentación y la brida superior del último tramo al rodamiento de yaw, fijado a la nacelle.

La estructura portante de cada tramo de torre se compone de chapas curvadas soldadas entre si, denominadas virolas, y de las bridas inferior y superior, también soldadas a las virolas.

Steel tower:

The steel tower is a tapered tubular structure and is composed of four or five sections. These sections are secured with the flanges located at their ends, and together they form the tower. The lower flange of the lower section is secured to the ring of foundation studs described above, and the yaw bearing, fixed to the nacelle, is secured to the upper flange of the upper section.

The structural components of each tower section are composed of curved plates welded together, called ring sections, and of lower and upper flanges, which are also welded to the ring sections.

El acceso al interior de la torre es posible a través de una puerta metálica situada en la parte inferior.

En el interior de la torre se encuentran una serie de componentes eléctricos y de control. Asimismo, el interior de la torre está iluminado en los puntos necesarios.

El diseño de la torre permite la instalación (de manera opcional) de un elevador en el interior de la torre, para facilitar el acceso a la nacelle y las labores de mantenimiento. No obstante, en todos los casos existe la posibilidad de acceso por escalera manual hasta lo alto de la torre. Esta escalera está provista de una línea de vida y demás elementos de seguridad.

The inside of the tower can be accessed through a metal door located in the lower section.

Inside the tower there are a number of electrical and monitoring components. Also, the internal part of the tower has lighting in the necessary areas.

The design of the tower enables the installation of a lift inside the tower, to facilitate access to the nacelle and maintenance operations. Nevertheless, in all cases it is possible to access the top of the tower using the ladder. The ladder is equipped with a lifeline and other safety elements.

3.3. Nacelle

La góndola o nacelle se sitúa en lo alto de la torre y se orienta según la dirección del viento gracias al sistema de posicionamiento (sistema de yaw). Todos los elementos que se describen a continuación se encuentran en su interior, albergados dentro de la carcasa de protección.

A la nacelle se accede desde el interior de la torre a través de una

3.3. Nacelle

The nacelle is located at the top of the tower and faces the direction of the wind by means of its positioning system (yaw system). All the elements described next are found inside the nacelle, sheltered under the protective cover.

The nacelle is accessed from inside the tower through a hatch and an trampilla y una escalera de acceso. Desde el interior de esta existe también un acceso al buje para poder realizar labores de comprobación y mantenimiento en él sin necesidad de salir al exterior.

access ladder. From the inside there is also access to the hub, in order to perform maintenance and verification operations without having to go outside the nacelle cover.

3.3.1. Carcasa de protección

La carcasa de protección de la góndola se fabrica en poliéster reforzado con fibra de vidrio.

En exterior de la carcasa en la parte superior trasera se sitúan el sensor ambiental (anemómetro) y la baliza o luz de gálibo.

La nacelle incorpora en el suelo de la parte trasera una trampilla y una pequeña grúa para permitir la elevación de repuestos o material diverso desde el suelo hasta la nacelle, facilitando las labores de mantenimiento.

Asimismo, existen varias trampillas-claraboyas distribuidas en la parte superior para posibilitar el acceso a los elementos de la parte exterior superior de la nacelle y para iluminación natural.

La carcasa de la nacelle dispone también de tres aberturas para

3.3.1. Nacelle protective cover

The nacelle protective cover is made of fibreglass-reinforced polyester.

The environmental sensor (anemometer) and the beacon or warning light, are located outside the nacelle cover in the upper rear part.

On the floor of the back of the nacelle there is a hatch and a small hoist to allow spare parts or equipment to be lifted from the ground up to the nacelle, facilitating maintenance operations.

There are also various hatches-windows distributed throughout the upper part that allow access to the elements of the nacelle outer upper part and to provide natural light.

The nacelle cover also has three cooling outlets, one in the back to refrigeración, una en la parte trasera para disipación de calor generado por el generador y otras dos en la parte superior para disipación de calor generado por la multiplicadora (intercooler de aceite).

release heat produced by the generator and another two on the upper part to release heat produced by the gearbox (oil intercooler).

Además de la iluminación natural a través de las claraboyas, el interior de la nacelle está iluminado eléctricamente.

In addition to the natural light provided by the windows, the inside of the nacelle is electrically lit.

La parte inferior de la carcasa tiene forma de bañera, de manera que cualquier sustancia líquida que se derrame en el interior de la nacelle se drene por el centro.

The lower part of the nacelle cover has a basin shape, so that any liquid spilled inside the nacelle drains through the centre.

Justo por debajo del rodamiento de yaw existe una canaleta que recoge dichas sustancias líquidas, conduciendo estas por una manguera a lo largo de la torre hasta un bidón de 50L situado en la base de la torre.

There is a channel just below the yaw bearing, where any liquid flows through a hose along the tower down to a 50L drum located in the tower base.

3.3.2. Bastidor delantero

La turbina AW3000 consta de dos bastidores: uno delantero y otro trasero. El delantero se apoya sobre la torre a través del rodamiento de yaw, y el trasero se encuentra a su vez atornillado al delantero. El bastidor delantero se fabrica en un solo bloque

3.3.2. Main Frame

The AW3000 turbine consists of two frames: the main frame and the generator frame. The main frame is supported on the tower by means of the yaw bearing, and the generator frame is bolted to it. The main frame is made of one single nodular cast-iron de fundición nodular de gran robustez que le permite soportar las elevadas cargas que el rotor transmite al eje principal y a la multiplicadora.

Directamente sobre él se apoyan sobre el mismo los siguientes componentes:

- Eje lento y rodamientos
- Grupo hidráulico
- Motorreductoras y corona de giro
- Armario superior de control.

block, which makes it very strong. It can withstand the torque that the rotor transmits to the low speed shaft and the gearbox.

The following parts are supported directly on the main frame:

- Low speed shaft and bearings
- Hydraulic power unit
- Yaw gears and yaw bearing
- Top controller cabinet

3.3.3. Bastidor trasero

El bastidor trasero va atornillado al delantero y sobre él se sitúa el generador.

3.3.3. Generator Frame

The generator frame is bolted to the main frame, and the generator is located on it.

3.3.4. Eje lento y rodamientos

El eje principal de la turbina AW3000 transfiere la energía del viento captada por el rotor en forma de energía cinética angular hasta la multiplicadora.

Con el fin único de evitar que las palas pudieran llegar a tocar la torre, en caso de altas velocidades de viento, el eje principal de la turbina AW3000 se coloca sobre el bastidor con una inclinación respecto de la horizontal de

3.3.4. Low speed shaft and bearings

The low speed shaft of the AW3000 turbine transfers the wind energy captured by the rotor, in the form of angular kinetic energy, to the gearbox.

To avoid the blades touching the tower, in the event of high wind speeds, the AW3000 turbine's low speed shaft is placed on the frame at an angle of 5º to the horizontal axis.

5º.

Dos soportes que se fijan al bastidor principal y que albergan a los dos rodamientos del eje lento, reciben el peso del eje y los esfuerzos del rotor. A su vez dichos esfuerzos se transmiten desde el bastidor principal hacia la torre.

El armario superior de control (top controller) va situado sobre el soporte de rodamiento trasero.

There are two supporting structures attached to the main frame that house the two low speed shaft bearings. They support the weight of the shaft and the stress of the rotor. In turn, this stress is transferred from the main frame to the tower.

The top controller cabinet is located on the rear bearing housing.

3.3.5. Multiplicadora y acoplamiento elástico

La función de la multiplicadora es transferir el par desde el eje lento hasta el eje rápido del aerogenerador aumentando la velocidad angular. El sistema de transmisión es de dos etapas planetarias y una paralela. El factor de multiplicación depende de la clase del aerogenerador, dado que el rango de velocidades angulares de operación del rotor depende del tamaño del rotor.

El eje rápido es fundamentalmente un acoplamiento elástico que conecta el eje de salida de la multiplicadora con el eje del generador. Este acoplamiento es capaz de transmitir la potencia en forma de par torsor y a la

3.3.5. Gearbox and flexible coupling

The gearbox transfers torque from the low speed shaft to the high speed shaft of the wind turbine, increasing the angular speed. The transmission system is composed by two planetary stages and one parallel stage. The gearbox ratio depends on the class of wind turbine because the angular speed range of rotor operation also depends on the rotor size.

The high speed shaft is a flexible coupling design that connects the gearbox output shaft with the generator shaft. It is capable of transmitting power in the form of torque and at the same time absorbing vez absorber desalineaciones de los ejes de la multiplicadora y del generador sin introducir grandes esfuerzos en dichos componentes.

shaft misalignments of the gearbox and of the generator, without putting great stress on these parts.

Además, el acoplamiento elástico está dotado de un limitador de par que impide la transmisión de sobrepares a la multiplicadora en caso de huecos de tensión.

In addition to this, the elastic coupling is provided with a torque limiter which avoids transmitting over-torque to the gearbox in the case of voltage dips.

La multiplicadora va literalmente colgada del extremo anterior del eje lento, y sus brazos de reacción se apoyan sobre el bastidor delantero en dos puntos.

The gearbox is directly attached to the rear end of the low speed shaft, and its torque reaction arms are attached to the main frame at two points.

Esta unión se realiza mediante unos soportes elásticos cuya función es amortiguar las vibraciones y reducir el ruido.

This union is made with elastic supports that absorb vibrations and dampen noise emissions.

La multiplicadora consta de su propio sistema de lubricación y refrigeración forzada. Con este sistema se lubrican y refrigeran engranajes y rodamientos mediante un circuito cerrado de aceite a presión y temperatura controladas con etapas de refrigeración y filtrado.

Este circuito se compone de:

- Una bomba accionada por un motor trifásico
- Filtros
- Bloque de válvulas

The gearbox has its own lubrication and forced cooling systems. With this system, the gears and bearings are lubricated and cooled by a closed oil circuit of controlled pressure and temperature with stages of cooling and filtration.

This circuit is composed of:

- A pump activated by a three phase motor
- Filters
- Manifold block

- Intercooler con ventilador
- Resistencia monofásica calefactora

La temperatura del aceite y los actuadores enumerados arriba están monitorizados y gestionados por la unidad de control.

En la parte trasera de la multiplicadora existe un freno de disco hidráulico y un sistema de bloqueo del tren de potencia.

- Intercooler with fan
- Single phase heater resistance

The temperature of the oil and the actuators listed above are monitored and managed by the controller.

At the back of the gearbox there is a hydraulic disc brake and a locking system for the mechanical power transmission.

3.3.6. Generador

El generador es un generador asíncrono trifásico de inducción, doblemente alimentado, de rotor devanado y excitación por anillos rozantes. Su potencia nominal es 3000kW y puede suministrarse para ser utilizado en frecuencias de red 50 y 60Hz.

El generador tiene 3 pares de polos y, por tanto, una velocidad de sincronismo de 1000rpm (50Hz) ó 1200rpm (60Hz).

La velocidad de giro del rotor es variable y se adapta a la velocidad del viento. No obstante, la potencia se suministra a la red siempre a 50/60Hz +2/-3 Hz y 12kV±10%.

Esto es posible adecuando la excitación rotórica a la velocidad angular del rotor, de manera que la potencia se genera a

3.3.6. Generator

The generator is a three-phase asynchronous induction generator, doubly-fed with winding rotor connected through slip rings. Its nominal power is 3000kW. It can be supplied for use in electrical grids of 50 Hz and 60Hz frequencies.

The generator has 3 pole pairs and, consequently, a synchronous speed of 1000rpm (50Hz) or 1200rpm (60Hz).

The rotational speed of the rotor is variable and adapts to the wind speed. However, power is always supplied to the grid at 50/60Hz +2/-3 Hz and 12kV±10%.

Power is generated at a constant voltage and frequency by adapting the rotor excitation to the angular speed of the tensión y frecuencia constantes.

El rango de velocidades del generador viene indicado en la correspondiente Especificación Técnica.

La característica más reseñable de este generador es que la potencia se genera a media tensión (12kV), lo cual ahorra transformadores y reduce pérdidas.

El Generador se apoya sobre el bastidor trasero mediante cuatro elementos amortiguadores (Silent-Blocks), cuya función es reducir la amplitud de las vibraciones y el ruido.

La refrigeración se lleva a cabo por ventilación forzada por medio de ventiladores para incrementar el intercambio de calor.

La temperatura en los devanados del estator, en el cuerpo de anillos rozantes, y en los rodamientos está monitorizada. La temperatura de dichos puntos se controla con ayuda de resistencias calefactoras y de los ventiladores mencionados anteriormente.

3.3.7. Sistema de yaw

La orientación de la nacelle con la dirección del viento predominante se lleva a cabo mediante el sistema de yaw. Este

rotor.

The generator speed range is indicated in the relevant Technical Specification.

The most notable characteristic of this generator is that power is generated in medium voltage (12kV), which reduces the need for transformers and reduces losses.

The generator is attached to the generator frame through four dampeners (silent blocks), which reduce the amplitude of the vibrations and noise.

Cooling of the system is carried out by forced ventilation through fans in order to increase heat exchange.

The temperature of the stator windings is monitored, in both the slip ring assembly and in the bearings. The temperature of these parts is controlled with help from the heater resistances and from the fans mentioned earlier.

3.3.7. Yaw system

The positioning of the nacelle towards the dominant wind direction is performed by the yaw system. It consists of a slewing consiste en una corona dentada solidaria a la torre y motorreductoras solidarias a la nacelle con sus respectivos piñones engranados en la corona de la torre, que hacen que la nacelle gire en ambos sentidos con respecto a la torre, sobre el rodamiento de yaw.

ring attached to the tower and yaw drives attached to the nacelle, with their respective pinions which gear with the tower bearing. These make the nacelle rotate in both directions on the yaw bearing around the tower axis.

Cada una de las motorreductoras se compone de un motor eléctrico trifásico de jaula de ardilla y un tren de engranajes reductores. Los motores constan asimismo de un freno eléctrico que está activado cuando no hay tensión.

Each of the yaw drives is formed by a three-phase cage motor and a gearbox. The motors also include an electric brake which is applied when there is no voltage.

El sistema de yaw se completa con un sistema de freno activo, realizado a través de pinzas de freno hidráulicas, que fijan mecánicamente la nacelle en la orientación correcta, y un disco de freno situado entre la torre y el rodamiento.

The yaw system is completed by an active brake system, consisting of hydraulic brake callipers that mechanically fix the nacelle in the correct position, and a brake disc positioned between the tower and the yaw bearing.

3.3.8. Sistema de Monitorización

El aerogenerador AW3000 está provisto de un sistema opcional de monitorización en continuo para su mantenimiento predictivo, mediante el cual se miden:

- Vibraciones en: Rodamientos del eje lento, multiplicadora (3 posiciones) y rodamientos de generador.
- Temperaturas en: Etapa de salida y cárter de la multiplicadora.

3.3.8. Monitoring System

The AW3000 wind turbine is provided with an optional monitoring system which continuously measures the following variables:

- Vibration: Low speed shaft bearings, gearbox (3 positions) and generator bearings.
- Temperature: Output stage and oil sump of the gearbox.

- Partículas metálicas y envejecimiento del aceite de la multiplicadora

3.3.9. Sistema de engrase centralizado

La lubricación de distintos elementos de la máquina se realiza en continuo y de forma automática mediante un sistema opcional de engrase centralizado, de forma que se garantiza la perfecta lubricación de los siguientes elementos:

- Rodamiento de yaw
- Engrane piñón – corona de yaw
- Rodamientos de pala
- Rodamientos de eje lento
- Rodamientos de generador

3.4. Rotor

La función del rotor es captar la energía del viento y convertirla en energía cinética de rotación.

El rotor del aerogenerador AW3000 se compone de tres palas montadas sobre un buje de fundición de hierro nodular, el cual está cubierto por el cono-nariz, de poliéster reforzado con fibra de vidrio.

Está diseñado para funcionamiento a barlovento.

Tal y como se ha indicado anteriormente, existen cinco variantes de rotor según el diámetro de la superficie que barren: 100,

- Metallic particles in gearbox oil, and gearbox oil life.

3.3.9. Central lubrication system

The lubrication of several components is done continuously and automatically by means of an optional central lubrication system; henceforth, the lubrication of the following elements is guaranteed:

- Yaw bearing
- Pinion – yaw bearing gear
- Blade bearing
- Low speed shaft bearings
- Generator bearings

3.4. Rotor

The rotor is used to take wind energy and convert it into rotational kinetic energy.

The rotor of the AW3000 wind turbine is made up of three blades mounted on a cast-iron hub which is covered by the nose cone, made of fibreglass-reinforced polyester.

It is designed for upwind operation.

As previously mentioned, there are five types of rotors, with swept area diameters: 100, 109, 116, 125 and 132 m. There are

109, 116, 125 y 132 m. El buje es el mismo en el caso de los rotores 100 (pala de 48.7 m) y 109 (pala de 53.2 m), pero diferente respecto a los de rotor 116 (pala de 56,7 m) y 125 (pala de 61,2 m). El buje de los rotores 132 (pala 64,7 m) es diferente a los de los otros rotores.

El rango de velocidades del rotor depende del diámetro de rotor de la máquina y del tipo de torre:

- AW 100/3000 TH100: Rango desde 9.9 rpm hasta 16.7 rpm.
- AW 109/3000 TH100 y T95.5: Rango desde 9.2 rpm hasta 15.5 rpm.
- AW 116/3000 TH100: Rango desde 10.1 rpm hasta 15.6 rpm.
- AW 116/3000 TH120 y T92: Rango desde 9.2 rpm hasta 15.6 rpm.
- AW 125/3000 TH100, TH120 y T87.5: Rango desde 9.2 rpm hasta 15.6 rpm.
- AW 132/3000 TH120: Rango desde 6.6 rpm hasta 12.5 rpm.

La velocidad del rotor se regula con una combinación de control de par resistente del generador (vientos bajos) y de control de pitch (vientos altos). El rotor gira en sentido horario mirando la turbina desde

two different hubs, one for rotors 100 (blade length 48.7m) and 109 (blade length 53.2 m), other for rotors 116 (blade length56.7 m) and 125 (blade length 61,2m). Hub for 132 rotor (blade length 64,7 m) is different to the other rotors ones

The rotor speed range depends on the rotor size and on the tower type:

- AW 100/3000 TH100: Range from 9.9 rpm to 16.7 rpm.
- AW 109/3000 TH100 and T95.5: Range from 9.2 rpm to 15.5 rpm.
- AW 116/3000 TH100: Range from 10.1 rpm to 15.6 rpm.
- AW 116/3000 TH120 and T92: Range from 9.2 rpm to 15.6 rpm.
- AW 125/3000 TH100, TH120 and T87.5: Range from 9.2 rpm to 15.6 rpm.
- AW 132/3000 TH120: Range from 6.6 rpm to 12.5 rpm.

The rotor speed is regulated by a combination of resistant torque control of the generator (low winds) and pitch control (high winds). The rotor rotates clockwise, when looking at the turbine from the front.

el frente.

Para evitar colisiones de la pala con la torre en caso de vientos altos, el rotor tiene una inclinación de 5º (tilt) respecto a la vertical, consecuencia de la inclinación del eje lento respecto a la horizontal.

To avoid the rotor blade colliding with the tower in the event of high winds, the rotor has a 5º inclination angle (tilt) to the vertical axis, a consequence of the low speed shaft inclination angle to the horizontal axis.

Integrado en el buje está el sistema de orientación de pala (pitch), de accionamiento independiente para cada una de las tres palas, que permite variar el ángulo de paso desde la posición de producción con la mayor superficie de pala expuesta al viento, a la posición de bandera-parada. Este sistema actúa también como freno aerodinámico, llevando las palas a posición de bandera.

The blade position system (pitch) is integrated in the hub and activates each of the three blades independently. This allows the pitch angle to vary from a position of production with largest blade area exposed to the wind, to feather position. This system also acts as an aerodynamic brake, bringing the blades into the feather position.

3.4.1. Buje

El buje, fabricado en fundición nodular, es el mecanismo que transmite la energía de las tres palas al eje lento. La unión del buje al eje lento es atornillada, con tres bulones adicionales de cortadura.

En el interior de este componente hueco se alojan los elementos que componen el sistema de pitch.

El buje dispone de 11 aberturas:

- 3 aberturas laterales para la inserción de rodamientos de pala

3.4.1. Hub

The hub, manufactured in nodular cast iron, is the mechanism that transmits energy from the three blades to the low speed shaft. The hub is attached to the low speed shaft by bolts, with three additional C-section shear pins.

The pitch system elements are located within the hub casing.

The hub has 11 openings:

- 3 openings on the sides for the insertion of the blade bearings

- 1 abertura frontal central para acceso al cono-nariz desde el buje.
- 3 aberturas frontales pequeñas para los cilindros de pitch
- 1 abertura trasera central para introducción de tubos de presión y cables para el sistema de pitch (conexión eje lento).
- Dependiendo el modelo de máquina, puede disponer de 3 aberturas traseras para acceso al buje directamente desde la nacelle.

- 1 opening at the front centre to access the nose cone from the hub
- 3 small openings at the front for the pitch cylinders
- 1 opening at the back centre for the insertion of pressure tubes and pitch system cables (low speed shaft connection).
- Depending of the model machine, could have 3 openings at the back in order to access the hub directly from the nacelle.

3.4.2. Palas

Cada turbina AW3000 tiene tres palas, conectadas al buje mediante sus respectivos rodamientos de pala. Las palas están fabricadas en fibra de vidrio reforzada con poliéster, con un recubrimiento superficial suave destinado a proteger los materiales de la radiación UV y a proporcionar el color a la pala. Cada pala está formada por dos cortezas unidas y soportadas por vigas y costillas internas.

Correspondiendo con los cinco diámetros de rotor disponibles comercialmente, existen cuatro longitudes de pala: 48,7 m,

3.4.2. Blades

Every AW3000 turbine has three blades, connected to the hub by their respective blade bearings. The blades are manufactured in polyester-reinforced fiberglass, with a smooth superficial coating intended to protect them from UV radiation and to keep their colour. Each blade comprises two joined sections, supported by beams and internal ribs.

There are five blade lengths corresponding to the four rotor diameters commercially available: 48,7 m, 53,2 m, 53,2 m, 56,7 m, 61,2 m and 64,7 m.

El perfil aerodinámico de las palas varía a lo largo de su eje longitudinal, tanto en sección y forma como en ángulo de incidencia del borde de ataque.

Unos insertos especiales de acero conectan la pala a la pista móvil del rodamiento de pala.

El rodamiento de pala permite el giro de la pala respecto a su eje longitudinal. Su pista fija está atornillada al buje y la móvil a la pala.

56,7 m, 61,2 m and 64,7 m.

The aerodynamic profile of the blades varies along its longitudinal axis both in the section and shape, such as in the incidence angle of the leading edge.

Special steel inserts connect the blade to the moveable ring of the blade bearing.

The blade bearing allows the rotation of the rotor blade with respect to its axis. Its fixed ring is bolted to the hub and the mobile one to the blade.

3.4.3. Sistema de pitch

El sistema de pitch permite variar el ángulo de paso de cada pala, al girar ésta sobre su eje longitudinal. Este sistema tiene dos objetivos:

- Regular la potencia generada con vientos altos
- Freno aerodinámico en caso de parada controlada o emergencia.

Normalmente se accionan las tres palas simultáneamente. Sin embargo, cada una de las palas del rotor tiene un sistema independiente de ajuste de ángulo de paso, accionado por un cilindro hidráulico específico para cada pala. Estos cilindros

3.4.3. Pitch system

The pitch system allows the pitch angle of each blade to vary, rotating on its axis. This system has two goals:

- To regulate the power generated in high winds.
- To brake aerodynamically in the event of a controlled or emergency stop.

Normally the three blades operate simultaneously. However, each of the rotor blades has an independent system for pitch angle setting, activated by a specific hydraulic cylinder for each blade. These cylinders are mounted onto the están físicamente ensamblados a las placas pitch, solidarias a la pista móvil de los rodamientos de pala, provocando con su actuación el giro de la misma.

pitch plates, connected to the mobile ring of the blade bearings, provoking their rotation when they turn.

Con el accionamiento independiente de cada pala se consigue un dispositivo de seguridad doblemente redundante, ya que con sólo una pala en bandera, se podría conseguir la detención el rotor.

Independent activation of each blade provides redundancy for the safety system. With only one blade in the feather position, the rotor can be stopped.

Cada pala tiene un acumulador de nitrógeno alojado en el buje, en el que hay una reserva permanente de aceite a presión suficiente para garantizar poder llevar la pala a bandera, incluso en el caso de falta de tensión de alimentación del grupo hidráulico (caída de presión en el sistema).

Each blade has a nitrogen accumulator located in the hub, where there is sufficient permanent supply of pressurized oil to ensure the blade can enter the feather position, even in the case of insufficient power supply from the hydraulic unit (system pressure drop).

Los componentes del sistema de pitch en el buje son:

- 3 cilindros hidráulicos para acciona-miento mecánico del giro de pala
- 6 acumuladores de aceite a presión con cámara de nitrógeno
- 3 bloques de válvulas para el accionamiento de los cilindros
- Sensores de posición de pitch (integrados en los cilindros)
- Circuitería hidráulica (latiguillos y/o tubos)
- Circuitería eléctrica y de

The components of the pitch system in the hub are:

- 3 hydraulic cylinders to mechanically activate the blade rotation
- 6 accumulators of pressurized oil with a nitrogen chamber
- 3 manifold blocks activate the cylinders
- Pitch position sensors (integrated in the cylinders)
- Hydraulic circuitry (hoses and/or tubes)
- Electric and communications circuitry

comunicaciones (cables y cajas de conexiones)

(wires and junction boxes)

3.4.4. Cono-nariz

El cono nariz protege el buje de las inclemencias meteorológicas. Está fabricado en poliéster reforzado con fibra de vidrio. El diseño de este cono-nariz junto con el del buje permite un acceso cómodo y seguro al interior del buje, sin necesidad de salir al exterior de la turbina.

El cono-nariz consta de dos partes, una principal con aberturas para las tres palas y la conexión al eje lento y otra que cierra el conjunto por su parte delantera.

3.4.4. Nose cone

The nose cone protects the hub from inclement weather. It is made of fibreglass-reinforced polyester. The design of the nose cone together with the hub allows safe and easy access to the internal part of the hub, without having to exit the turbine.

The nose cone consists of two sections: a main section with holes for the three blades and the connection to the low speed shaft, and another section that closes the assembly at its front.

4. FUNCIONAMIENTO

El control que incorpora la turbina AW3000 funciona básicamente como se describe a continuación (modo automático).

Con vientos bajos, la velocidad de giro del rotor es proporcional a la velocidad del viento. Cuanto mayor es la velocidad del viento, mayor es la velocidad de giro del rotor, controlando ésta mediante el denominado “control de par”. El par resistente del generador es el que

4. OPERATION

The AW3000 turbine has a control that operates predominantly as described next (automatic mode).

In low winds, the rotational speed of the rotor is proportional to the speed of the wind. The higher the wind speed, the higher the rotational speed of the rotor. The factor controlling this is called “torque control”. Due to the resistant torque of the generator the rotor speed is controlled to mantiene la velocidad del rotor en su valor de referencia.

its reference value.

Este control se utiliza desde el momento en que el aerogenerador entra en producción hasta que la potencia producida por el generador alcanza su valor nominal (3000kW). En esta fase, la potencia producida es directamente proporcional a la velocidad del viento.

This control is used from the time the wind turbine enters production until the power produced by the generator reaches its nominal value (3000kW). At this stage, the power produced is directly proportional to the wind speed.

Con vientos altos, la velocidad del rotor se mantiene constante en su valor nominal (máximo).

In high winds, the rotor is maintained at a constant speed at its nominal value (maximum).

Dado que en estas condiciones el generador se encuentra saturado entregando la potencia nominal y no puede ofrecer un par resistente mayor, el control de la máquina se realiza regulando el ángulo de paso de las tres palas. Este es el denominado “control de pitch” que, mediante control aerodinámico, mantiene la potencia volcada a la red constante e igual a la potencia nominal (3000kW) hasta llegar a la velocidad de corte.

Given the fact that in these conditions the generator is saturated, delivering nominal power and cannot provide greater resistant torque, the turbine is controlled by adjusting the pitch angle of the three blades. This is called “pitch control” and, by aerodynamic control, maintains the power supplied to the grid constant and equal to the rated power (3000kW) until reaching the cut-out speed.

A continuación se describen más detalladamente diferentes aspectos del funcionamiento de los aerogeneradores AW3000.

Below, various functional aspects of the functioning of the AW3000 wind turbines are described in more detail.

4.1. Red eléctrica

4.1. Electrical grid

Las condiciones nominales de la red a la

The nominal conditions of the grid that the que debe conectarse el aerogenerador son 12 kV, 50Hz ó 60Hz.

El intervalo de tensión en funcionamiento debe estar comprendido entre +10/-10% del valor nominal. El intervalo de variación en frecuencia es de +2/-3 Hz.

La red eléctrica debe ser suficientemente estable (dentro de los márgenes mencionados) puesto que variaciones frecuentes de tensión o frecuencia más allá de los límites en operación pueden causar daños en los componentes mecánicos de la máquina.

En caso de pequeñas redes eléctricas independientes, será necesario comprobar las condiciones reales.

En todas las condiciones de operación se puede obtener un factor de potencia unitario a la salida del cuadro de 12kV y una conexión a la red eléctrica muy suave, gracias a su rutina de sincronización a red.

En la cimentación se integra una conexión a tierra de máximo 10Ω, adaptando la topología de la red a las características del terreno.

wind turbine must be connected to are 12kV, 50Hz or 60Hz.

The voltage interval in operation must be between +10/-10% of the nominal value. The frequency variation interval is +2/-3Hz.

The electrical grid must be sufficiently stable within the margins mentioned since frequent voltage or frequency variations can damage the mechanical components of the turbine.

In the case of small independent electrical grids, actual conditions must be checked.

In all operational modes, a power factor of 1 is obtained at the output of the 12kV panel and a regulated electrical grid connection because of the grid synchronization routine.

In the foundation there is an integrated earthing connection maximum of 10Ω, adapting the grid topology to the characteristics of the site.

4.2. Sistema de generación

El sistema de generación eléctrica es de velocidad variable, y asegura que la

4.2. Generation system

The electricity generation system is variable speed, and ensures that the velocidad y el par mecánico del aerogenerador siempre suministren a la red una potencia eléctrica estable. El funcionamiento se explica a continuación.

speed and the mechanical torque of the wind turbine always supplies stable electric power to the grid. Its operation is explained below.

El estator está directamente conectado a la red. El rotor bobinado se alimenta con una señal controlada en amplitud y frecuencia, producida por el equipo electrónico de potencia. Las corrientes rotóricas se introducen en el rotor mediante anillos rozantes.

The stator is directly connected to the grid. The rotor winding is fed with a signal controlled in both amplitude and frequency, produced by the electronic power converter. The rotor currents are introduced into the rotor through slip rings.

La velocidad del giro del rotor se optimiza con relación a la del viento. El equipo de potencia a su vez adecua la magnetización del rotor a la velocidad del mismo, generando en el estator la potencia a la tensión y frecuencia deseadas.

The rotational speed of the rotor is optimized in relation to that of the wind. The power converter adapts the magnetization of the rotor to its speed, generating power in the stator to the desired voltage and frequency.

Dado que la excitación del rotor está controlada por el equipo de potencia, el generador puede funcionar por encima y por debajo de la velocidad de sincronismo. En régimen subsíncrono, el rotor consume energía de la red y en régimen hipersíncrono produce energía que es entregada a la red.

Given the power converter controls the rotor’s excitation, the generator can operate within and below the synchronous speed. In subsynchronous operation, the rotor uses energy from the grid and in hypersynchronous operation it supplies energy to the grid.

En todo caso, el generador es visto como síncrono desde la red. El control de corrientes rotóricas permite también el control del factor de potencia, que se puede imponer como un parámetro

From the grid, the generator is seen as synchronous in all cases. The control of rotor currents also allows the control of power factor, which can be considered as a parameter defined by the monitoring definible por el sistema de control.

Otro resultado de la generación síncrona que caracteriza al sistema de generación es la “suave” conexión a la red eléctrica. Estas conexiones suaves se consiguen mediante una rutina de sincronización a la red, en la que se genera una tensión en el estator del generador igual a la de red en magnitud y fase, con lo que se conecta a red con corriente de conexión cero, y con simples contactores, sin ser necesario equipo adicional como tiristores en el caso de grupos asíncronos convencionales.

system.

Another result of the synchronous generation that characterizes the generation system is the “smooth” connection to the electrical grid. You can achieve these smooth connections by a “grid synchronization” routine. This generates voltage in the generator stator in magnitude and phase equal to that of the grid. This connects the generator to the grid at zero current by means of standard contactors, which makes any additional equipment unnecessary, such as thyristors in the case of conventional asynchronous groups.

Como resultado del control de par mecánico se pueden reducir las cargas en el tren de potencia, permitiendo absorber el exceso de energía de las ráfagas de viento trasformándolo en energía cinética de rotación en el rotor que permite la autoinducción y la entrega de energía a red desde el rotor en régimen hipersíncrono.

As a result of the mechanical torque control, the loads in the mechanical power transmission can be reduced. This allows the excess energy from gusts of wind to be absorbed. It is then transformed into rotational energy in the rotor, which allows the supply of energy to the grid from the rotor in the hyper-synchronous system.

Asimismo se consigue disminuir el nivel de ruido debido a la menor velocidad de giro del rotor en vientos bajos, en los que el aporte de ruido medioambiental del aerogenerador podría ser bien perceptible respecto al nivel de ruido de fondo

Also, noise levels are reduced because of the lower rotational speed of the rotor in low winds. The noise of the wind turbine could be highly perceptible when compared to the background noise caused by the wind.

causado por el propio viento.

4.3. Unidad de control y potencia

La unidad de control y potencia, basada en el sistema INGECON-W o DTC, monitoriza y controla todas las funciones críticas del aerogenerador, para optimizar constantemente el funcionamiento del mismo en todo el rango de velocidades del viento. Se sitúa en la base de la torre, en el interior de un armario eléctrico, comúnmente llamado "Ground".

La unidad de control y potencia puede descomponerse en dos, tal y como indica su nombre:

- La unidad de control, que consta de un PLC (Programmable Logic Controller), y que es la encargada de controlar toda la máquina
- La unidad de potencia, que trabaja en comunicación con el PLC. Consta de una CCU (Converter Control Unit) y de un equipo de potencia al que controla.

El PLC y la CCU se hallan constantemente comunicados y coordinados entre sí. Asimismo, el armario ground está preparado para conectar una pantalla táctil opcional que aporta una interfaz al usuario.

4.3. Controller and power unit

The controller and power unit, based on the INGECON-W or DTC system, monitors and controls all the critical functions of the wind turbine, to constantly optimize its operation throughout the range of wind speeds. It is located in the base of the tower, inside an electrical cabinet, which is commonly called the "ground controller".

The controller and power unit can be divided into two parts, as their name indicates:

- The controller, that has a PLC (Programmable Logic Controller), and is responsible for controlling the entire turbine
- The power unit, that communicates with the PLC. It has a CCU (Converter Control Unit) and a power converter controlling it.

The PLC and the CCU are constantly communicating and coordinated with each other. Additionally, the ground cabinet is prepared to connect an optional touch screen so that the user can have an interface.

4.3.1. Unidad de control

El PLC junto con sus tarjetas de entrada/salida capta las señales de las diversas funciones del aerogenerador, calcula las acciones de control óptimas y da las órdenes a los actuadores correspondientes (motores, electroválvulas, relés...) para conseguir el funcionamiento seguro y la mejor captación de la energía eólica disponible en el emplazamiento. También es el encargado de activar la parada de emergencia en caso de que la turbina no funcione correctamente.

Las funciones principales de la unidad de control (PLC) son:

- Orientación de la góndola respecto al viento predominante. Supervisión y corrección del estado de torsión de los cables de la torre.
- Gestión del grupo hidráulico que proporciona energía mecánica al sistema del pitch y a los frenos del sistema yaw y de eje rápido.
- Supervisión de los sensores ambiente: viento, dirección predominante de viento, temperaturas.
- Supervisión de la velocidad de giro

4.3.1. Control unit

The PLC and its input/output cards detect the signals of the wind turbine's various functions, calculate the optimal control actions and give orders to the actuators (motors, electrically operated valves, relays, etc.) to obtain secure operation and the most efficient capture of available energy. It is also in charge of activating the emergency stop in the event of the turbine not working properly.

The main tasks of the controller (PLC) are:

- Positioning the nacelle towards the prevailing wind. Monitoring and correcting the torsion condition of the tower wires.
- Managing the hydraulic unit that provides mechanical energy to the pitch system and to the yaw and high speed shaft brakes.
- Monitoring the environmental sensors: wind, prevailing wind direction, temperatures.
- Monitoring the rotational speed of

de los diferentes componentes mecánicos.

- Supervisión y monitorización del estado de vibraciones.
- Supervisión de las funciones del generador y del convertidor. Conexiones y desconexiones a red.
- Consignas de potencia activa y reactiva.
- Regulación de la velocidad.
- Posicionamiento y control del ángulo de pitch (palas).
- Control de alarmas y modo de operación.
- Intercambio de datos con Telemando.
- Contadores de energía, horas y disponibilidades.
- Gestión de parámetros de la turbina.

the various mechanical components.

- Monitoring and testing the state of vibrations.
- Monitoring the generator and converter functions. Connecting to and disconnecting from the grid.
- Setting the active and reactive power.
- Regulating speed.
- Positioning and controlling the pitch angle (blades).
- Monitoring alarms and operating mode.
- Exchanging data with the remote control.
- Monitoring power meters, hours and availability.
- Managing the turbine parameters.

4.3.2. Unidad de potencia

La unidad de potencia está compuesta por los siguientes elementos:

- Equipo de potencia (convertidor)
- CCU
- Medida de tensiones y corrientes
- Medida de velocidad (Encoder)
- Protecciones contra sobretensiones

4.3.2. Power unit

The power unit consists of the following elements:

- Power converter
- CCU
- Pressure and current monitor
- Speed monitor (Encoder)
- Protection against overvoltage in the

en el convertidor

- Sistemas de refrigeración
- Contactores de alimentación
- Contactor de acoplamiento del estator a red

El equipo de potencia consta fundamentalmente de un convertidor rectificador de entrada desde la red, una batería de condensadores para el almacenamiento de carga en forma de tensión continua y un convertidor inversor de salida hacia el rotor. En régimen hipersíncrono, el flujo de energía a través del equipo de potencia se invierte, aportando el rotor energía a la red.

converter

- Cooling systems
- Power supply contactors
- Stator to grid contactor

The power converter is basically an input rectifier converter from the grid, a capacitor bank for load storage in the form of continuous voltage and an output inverter converter to the rotor. In hypersynchronous operation, the energy flowing through the power converter is inverted, bringing the rotor energy to the grid.

4.4. Modos de operación

Los aerogeneradores AW3000 tienen tres modos o sublógicas de operación, que se describen a continuación:

- Modo Automático
- Modo Manual
- Modo de Emergencia

4.4. Operational modes

The AW3000 wind turbines have three modes or operation sublogic, that are described below:

- Automatic mode
- Manual mode
- Emergency mode

4.4.1. Modo automático

El modo automático es el modo normal de funcionamiento (autónomo) de la turbina.

Al reiniciar la máquina en modo automático, la máquina pasa por tres

4.4.1. Automatic mode

Automatic mode is the normal operation mode (autonomic) of the turbine.

To restart the turbine in automatic mode, the turbine goes through three phases:

fases:

- Ensayo
- Pausa (una vez completado el ensayo)
- Marcha (cuando las condiciones de viento son propicias)

- Test
- Standby (once the test is complete)
- Run (when the wind conditions are favourable)

En fase de pausa, las palas están en posición de bandera, de tal forma que no recogen la energía del viento.

Cuando la velocidad de viento alcanza la velocidad de necesaria para el arranque (dependiente de la clase de la turbina), la turbina pasa de la fase de pausa a marcha. Esto significa que las palas se mueven a la posición de 0º, recogiendo la mayor cantidad de viento posible.

Cuando las palas se posicionan a 0º, el rotor empieza a acelerarse. Cuando el generador alcanza la velocidad de acoplamiento, comienza a entregar energía a la red.

Si la velocidad del viento aumenta, por medio de la variación en la excitación del rotor del generador, se va adecuando el par resistente del generador de forma que la velocidad de rotación del tren de potencia aumente hasta llegar a la velocidad nominal del generador.

Este tipo de control es el denominado

In standby, the blades are in feather position so that they do not capture wind energy.

When the wind speed reaches the cut-in level (depending on the turbine class), the turbine switches from standby to run. This means that the blades move into the 0º position, capturing the largest amount of wind possible.

When the blades are positioned at 0º, the rotor begins accelerating. When the generator reaches the coupling speed, it starts supplying energy to the grid.

If the wind speed increases, through the variation in the generator rotor excitation, the resistant torque of the generator is adapted so that the turning speed of the mechanical power transmission increases up to nominal speed of the generator.

This type of control is called “torque

"control de par", que ya fue mencionado anteriormente. Se utiliza hasta que se alcanza la potencia nominal del generador.

Para velocidades de viento superiores a las correspondientes a este punto, se regula la velocidad de giro del rotor mediante el control del ángulo de pitch de las palas, manteniendo la velocidad nominal y la máxima potencia en el generador. Este tipo de control es el denominado "control de pitch".

El sistema de pitch continúa regulando hasta que se alcanza la velocidad de corte. (Dependiente de la clase de la turbina). En ese momento se vuelve a la fase de pausa, dirigiendo las palas a posición de bandera.

control", mentioned previously. It is used until the generator's nominal power.

For wind speeds higher that this amount, the rotational speed of the rotor is adjusted by the pitch angle control of the blades, maintaining the nominal speed and maximum power in the generator. This type of control is called "pitch control".

The pitch system continues adjusting until the cut-out wind speed is reached (depending on the turbine class). At this point it returns to standby, moving the blades into feather position.

4.4.2. Modo manual

El modo manual se emplea para realizar pruebas de mantenimiento de la máquina. Trabajando en este modo, el usuario puede manejar manualmente todos los subsistemas de la máquina desde la pantalla táctil de mantenimiento conectada al armario ground. No obstante, en este modo, el PLC continúa supervisando por seguridad todas las operaciones.

4.4.2. Manual mode

Manual mode is used when performing turbine maintenance tests. While working in this mode, users can manually manage all the subsystems of the turbine from the maintenance touch screen connected to the ground controller.

Nevertheless, the PLC continues supervising all operations for safety in this mode.

4.4.3. Modo emergencia

El modo emergencia se alcanza cuando se abre la denominada serie de emergencia, que se activa cuando cualquiera de los sensores de los que dispone la máquina detecta algo anómalo (nivel de vibraciones, sobrevelocidad, etc.), o se pulsa alguno de los pulsadores de parada de emergencia.

En modo emergencia, la máquina se encuentra en reposo y segura.

Este modo debe desactivarse imperativamente por medio de accionamiento manual, tras inspeccionar la máquina.

4.4.3. Emergency mode

Emergency mode is reached when the safety system is enabled, when any of the turbine sensors detect an abnormal situation (level of vibrations, overspeed, etc.) or when one or more of the emergency stop buttons is pressed.

In emergency mode the turbine is not operating and secure.

This mode must be disabled by manual activation, after the turbine inspection.

Technical Review of the Acciona AW3000 Wind Turbine Platform

Acciona Windpower

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Green Pastures Wind Farm, TX, USA

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E-F	26 March 2015	Minor updates, issued as Final	P. Brodeur	S. Wright	S. Wright
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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)
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
DNV GL	Garrad Hassan America, Inc.
HALT	Highly accelerated life test
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
RCA	Root cause analysis
SCADA	Supervisory control and data acquisition
SoC	Statement of Compliance
SQE	Supplier quality engineering
TBD	To be determined
UT	Ultrasonic testing
WTG	Wind turbine generator

EXECUTIVE SUMMARY

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, Acciona Windpower, in 1999. Acciona Windpower (also referred to here as "the wind turbine manufacturer", "Acciona" or "AWP") is the focus of this report. Acciona Windpower's first wind turbine was installed in 2000, and significant commercial installations began in 2004, mostly for Acciona wind projects. In 2006, AWP started to sell a significant portion of its wind turbines to third parties. AWP can directly manufacture blades and concrete towers (through subsidiaries Acciona Blades and Acciona Infrastructure, respectively) and assembles nacelles and hubs. Acciona subcontracts all other manufacturing. DNV GL 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 invested in prototyping (14 wind turbine generators (WTG)) and industrialization to prepare for commercial deployment. The design of the AW3000 is based on Acciona'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 turbine design, although it represents twice the nameplate rating and is available with a range of larger rotor options.

The Acciona AW3000 turbine platform includes five rotor diameters: the AW100/3000, the AW109/3000, the AW116/3000, the AW125/3000 and the AW132/3000, although the AW109/3000 is not currently being offered commercially. 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 Acciona 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. 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 Navarra, Sierra de Alaiz, Spain. Commercial installations of the AW3000 platform began in late 2012 and, as of the end of Q2 2015, global installations of the platform comprise approximately 357 turbines (1,071 MW).

Acciona has well established engineering, manufacturing, and field service capabilities. With more than 170 turbine-years of experience worldwide as of the end Q2 2015, and based on the availability data reviewed and Acciona's demonstrated experience with operations of turbines in North America (based on the AW1500 fleet of turbines), DNV GL considers the AW116/3000 turbine to be qualified in North America. DNV GL would expect the AW116/3000 turbine to proceed and mature as many of the other turbine models have done in the industry, and progress to *proven* status as the turbine gains experience. DNV GL considers AW3000 with smaller rotor size (100 m, 109 m) to be qualified in North America as well.

DNV GL may also consider the turbine to be qualified in other regions or countries where Acciona has well established and demonstrated O&M and service capabilities. With a significant installed base and headquarters located in Spain, DNV GL can consider the AW100, AW109 and AW116/3000 turbines to be qualified in Spain. Status for other countries or regions may be reviewed by DNV GL on a project-specific basis.

DNV GL recommends assuming a one-year ramp-up in availability after commissioning, with nominal technical turbine availability of 96% being achieved for the Acciona 3.0 MW turbines, 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 five, with declining levels expected in subsequent years.

1 INTRODUCTION AND BACKGROUND

1.1 Objectives of this report

DNV GL 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 GL archives;
- Information provided by the wind turbine manufacturer; and
- Information obtained by DNV GL 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 GL cannot be held responsible for the accuracy of information supplied by turbine manufacturers; however, DNV GL has applied a test of reasonableness to the information and if there are any obvious errors, these have been indicated in the text.

2 COMPANY PROFILE

2.1 Company history

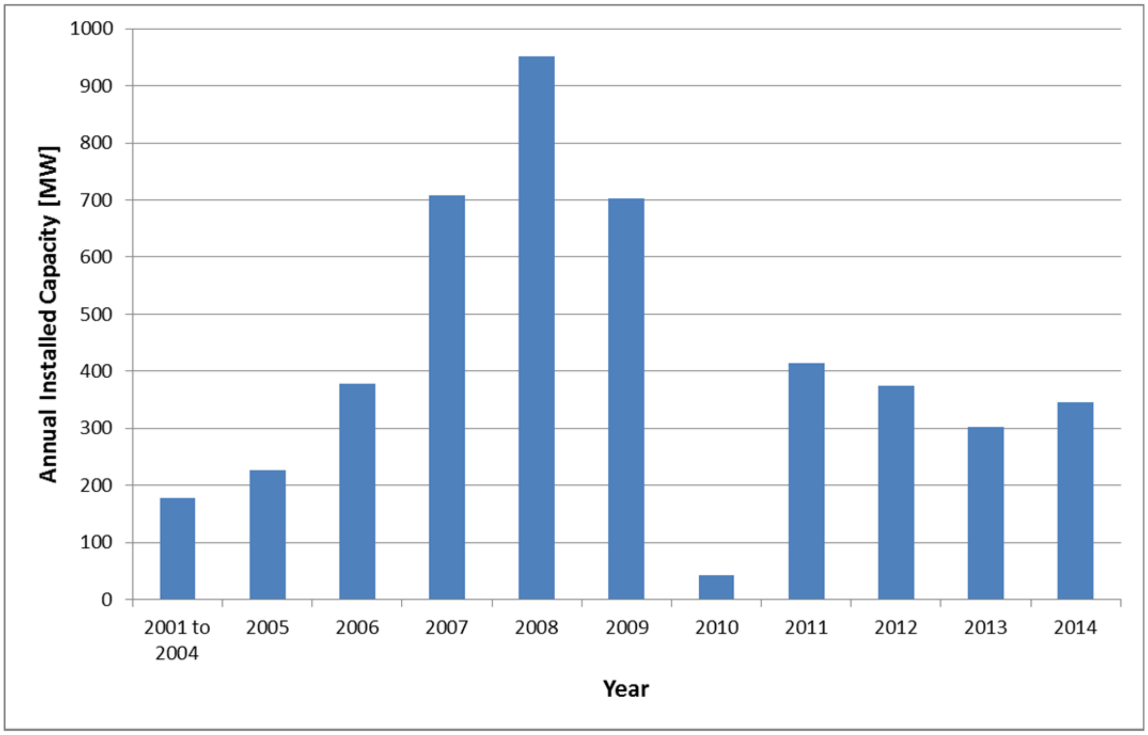
The Spanish infrastructure conglomerate, Acciona S.A., has several subsidiaries involved in the wind industry, including Acciona Windpower (also referred to here as "the wind turbine manufacturer", "Acciona" the Company, or "AWP"), which is the focus of this report. The Company is headquartered in Pamplona, Navarra, Spain. There are also a number of affiliated companies, such as Acciona Windpower North America.

Two related companies are referenced 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 became Acciona Windpower.

Figure 2-1 presents the annual and cumulative installed capacity of AWP turbines, from 2000 to the end of 2014. Acciona's record year for installations (in MW) was 2008; according to BTM Consult [1], this made AWP eighth in the world for installed capacity for that year, with a market share of 4.6%. DNV GL considers that the slowdown in the installation of turbines in the Spanish market has had a negative impact on Acciona's installation figures. In addition, the wind turbine market as a whole has become more competitive in Acciona's primary markets, due to the general global financial situation. During the slower period of commercial activity, AWP focused on multi-year effort of development, prototyping, and measurement for the AW3000 platform. Serious commercial deployment of the AW3000 did not begin until 2011.



Source: Acciona Global Track Record Database 4Q2014 [3]

Figure 2-1 Acciona installation history worldwide

2.2 Turbine product line

Acciona's current wind turbine offerings are shown in Table 2-1. This report is focused on the AW3000.

Table 2-1 Acciona product line

Turbine platform	Power [MW]	Rotor diameter [m]	IEC Class
AW1500	1.5	70	IA
		77	IIA
		82	IIA
AW3000	3.0	100	IA
		116	IIA
		125	IIB/IIIA/IIIB
		132	IIIB

Note: While 17 have been installed to date, the AW109/3000 is no longer commercially available.

2.3 Acciona technical and manufacturing capabilities

Acciona S.A.'s involvement in wind power has traditionally 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 Acciona 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, Acciona 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.

As discussed in further details below, DNV GL visited Acciona at multiple occasions, including meetings and discussions in February 2015 at Acciona's headquarters and visits to Acciona's nacelle and blade facilities, all located near Pamplona, Spain. DNV GL notes that during these visits and meetings, Acciona was responsive to DNV GL's questions, and provided the required documentation, showing transparency during the whole process. DNV GL considers Acciona's openness to be a positive element of this review.

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 16 years. The engineering team 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 wind turbines of other OEMs.

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 those that had been proven according to these criteria 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 design feature was introduced based on the input of wind farm developers and operators. Another significant innovation is concrete towers, with hub height up to 137 m.

2.3.2 Quality control

AWP holds an ISO 9001:2008 quality system certificate for the design, manufacture, assembly, and commissioning of wind turbines at its Spanish facilities; the certificate was issued by Bureau Veritas and is valid until 13 August 2015. These facilities also have a system of environmental management that complies with the requirements of ISO 14001:2004 and a health and safety accreditation that complies with OHSAS 18001:2007, both also certified by Bureau Veritas, with certificates valid until August 2015. In general, DNV GL finds that the quality management system and its certification are in line with the industry standard. Acciona'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 Acciona Windpower North America is covered under separate certificates, although it includes the same three certifications: ISO 9001:2008, ISO 14001:2004, and OHSAS 18001:2007, all issued by Bureau Veritas and all valid until 23 October 2016.

2.3.3 Turbine manufacturing and supply chain

AWP's manufacturing consists mainly of assembling nacelles and hubs, manufacturing concrete towers (through Acciona Infrastructure, a subsidiary of Acciona S.A.), and producing a portion of the rotor blades for the AW1500 and AW3000 platforms. Acciona produces blades for the AW116/3000, AW125/3000 and AW132/3000 turbines through Acciona Blades located in Lumbier, Spain, a subsidiary of Acciona S.A. AWP assembles turbine nacelles and hubs at the following facilities: Barásoain (Navarra, Spain), opened in May 2005, and la Vall d'Uixó (Castellón, Spain), also opened in 2005. AWP reports a production capacity of 600 MW per year at each of these facilities. 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. AWP also recently opened a production facility for hubs and nacelles in Brazil. AWP had a manufacturing plant in China; however, AWP sold this facility in 2009.

AWP subcontracts all other manufacturing, including the manufacture of Acciona's own blade design using the "build-to-print" concept for the AW116, AW125 and AW132 blades, working in partnership with Aeris and Tecsis in Brazil and TPI in China. LM currently produces blades for the AW100/3000 model, which is an LM blade design. As of Q2 2015, there are nine molds available globally for the AW3000 platform.

Acciona's manufacturing concept, working with multiple subcontractors, is similar to that employed by other turbine manufacturers, both large and small. Table 2-2 presents Acciona's suppliers for the AW3000 major components.

Table 2-2 Major component supply chain

<table>
<tr><th>Component</th><th>AW100/3000</th><th>AW116/3000</th><th>AW125/3000</th><th>AW132/3000</th></tr>
<tr><td>**Blades**</td><td>LM</td><td colspan="3">In-house design, Acciona manufacturing (Spain)
or built-to-print by TPI (China), Aeris and Tecsis (Brazil)</td></tr>
<tr><td>**Gearbox**</td><td>Moventas</td><td colspan="3">Winergy, Moventas</td></tr>
<tr><td>**Generator**</td><td colspan="4">INDAR, ABB</td></tr>
<tr><td>**Main bearing**</td><td>Laulagun, Liebherr, Rothe Erde</td><td colspan="3">Laulagun, Liebherr, Rothe Erde, SKF, FAG</td></tr>
<tr><td>**Converter**</td><td colspan="4">Ingeteam, ABB</td></tr>
<tr><td>**Controller**</td><td colspan="4">Ingeteam, Bachmann, Acciona</td></tr>
</table>

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 GL's perspective on both the design and manufacturing quality of the turbines.

Like most turbine manufacturers, AWP is routinely looking for new suppliers. At a meeting in 2010 and again in February 2015, AWP presented its procedure for the introduction of new suppliers to DNV GL. 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 GL finds that the supply chain for AWP turbines is managed in accordance with industry standard practice.

2.3.3.1 Nacelle assembly, Acciona Windpower facility, Barásoain, Spain

DNV GL visited the Barásoain assembly plant in March 2011, in June 2014 and again in February 2015; DNV GL 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. In April 2010, DNV GL visited the North American assembly plant in West Branch, Iowa, and reached similar conclusions. While a broader role is envisaged for the future, at the present time the West Branch facility mainly performs the final assembly of parts that were received and largely assembled at the Spanish plants.

The Barásoain facility first started operations in 2003 with the AW1500 platform wind turbines. Currently, nearly all nacelles and hubs produced at Barásoain are for the AW3000 turbine model. The facility production capacity is 7 nacelles per week if crews are working 7 days per week on 3 shifts. The facility currently employs 392 employees [4]. An overview of the assembly facilities is shown in Figure 2-2.

Figure 2-2 Overview of the Barásoain nacelle and hub assembly facility

During the Barásoain facility visit on 11 February 2015, DNV GL toured the facility, discussed Acciona's quality management system and observed this system as it is put into practice in the nacelle assembly facility. The conformity of the nacelles and hubs to quality specifications is controlled within the manufacturing process itself. The production flow within the facility is based on a "pulse" or "takt" system where the nacelle or hub is moved on a schedule (pulse) from one assembly station to the next. Acciona monitors the quality of the assembly during the production flow at critical points in each pulse. For example, DNV GL observed the hub preassembly pulse, in which the pitch bearing bolts are tensioned and machined surfaces are painted. Bolt tensioning is considered a critical operation and Acciona has specific controls for this operation. Once activities are complete in a pulse, the components move to the next station to continue assembly.

Acciona 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. This type of testing can be considered to be industry standard practice. A final inspection is carried out at the end of this pulse, which generates a quality certificate that is delivered with the final inspection records to the client.

Once fully tested and approved, all nacelles and hubs are stored in the outdoor lay-down area with appropriate tarps, ready to be shipped by road.

DNV GL also reviewed a sample of the quality assurance documentation and procedures in place at the Barásoain facility and found them to be in line with the industry standard. Based on the nacelle assembly plant visit, as well as review of quality documentation and discussion with Acciona’s quality department in the Barásoain facility, DNV GL considers this facility to be clean, well-organized, and equipped with appropriate, industry-standard quality practices. Testing of assembled nacelles appears to be on par with industry standard, including rotational testing at nominal generator speed.

2.3.3.2 Blade manufacturing, Acciona Blade facility, Lumbier, Spain

In 2009 AWP opened a new facility for manufacturing its own blade design in Lumbier, Spain, under the name Acciona Blades, which is a direct subsidiary of Acciona S.A. According to Acciona, the facility is capable of producing approximately 140 blade sets for the AW3000 per year, when operating at seven days per week and 120 sets/year if operating six days per week. The facility is currently near maximum staff capacity with 415 employees. This facility has ISO 9001 and 14001 as well as OSHAS certifications.

DNV GL visited the Lumbier blade manufacturing facility in June 2014 and February 2015, with an overall finding that manufacturing practice was on par with or superior to the industry norm. Tooling is of good quality. Material suppliers are qualified by Acciona before any of that suppliers’ material may be used in the manufacturing processes. All materials are inspected and tested by the Acciona quality department. In manufacturing, fabric cutting is performed on cutting machines into the shapes required. The process is automatic and DNV GL considers this process to be state of art. Automated fabric cutting eliminates the risk of errors due to manual fabric cutting.

A manual ultrasonic A-scan is performed for 100% inspections of shear webs, leading edge and trailing edge bond quality. Ultrasonic inspection of 100% of the bonding area is considered by DNV GL to be industry best practice. Poor adhesive bonds are a leading cause of blade failures in service, and DNV GL sees this level of inspection as a risk-reducing element for these blades. Ultrasonic testing (UT) is also used to characterize any wrinkles detected visually in spar caps.

During the visit, DNV GL observed that critical-to-quality (CTQ) items were clearly posted along with related process instructions. Statistical process control is clearly used, with posters showing trends in manufacturing parameters such as person-hours per blade, number of repairs, labor-hours associated with repairs, and adhesive quantities. Production statistics indicate recent improvement in multiple CTQs including voids in bond lines.

During the Acciona Blades facility visit on 12-13 February 2015, DNV GL discussed Acciona quality management system and observed this system as it is put into practice in the blade manufacturing facility. The conformity of the blades to quality specifications is controlled within the manufacturing process itself. Production workers are responsible for executing production tasks, performing quality control functions, and recording control check results. The production workers are monitored by team leaders, who are responsible for the overall processes and recording of the results of quality records. This quality control strategy is similar to automotive industry practices. The role of the quality department is to ensure that production workers have access to the most up-to-date procedures and checklists, and to review key performance indicators, in order to improve and optimize processes.

The work instruction is the main document used for process control. The work instructions include: process instructions, quality instructions, hazards prevention instructions, and environmental instructions.

During the visit, DNV GL reviewed sample quality control documentation, which was observed to be consistent with standard industry practice. DNV GL observed that all of the documents requested were produced quickly. Work instructions were present at the work stations and the quality control checklists that travel with the components were observed to properly reflect the progress of the component in the assembly process.

DNV GL also inspected finished blades in the lay-down yard, and while no significant deviations to quality were noted, DNV GL considers that the overall finish of some blades is not consistent with industry best practice. While paint quality on all finished blades met Acciona quality requirements, DNV GL noted multiple areas that had been re-painted. It is noted that Acciona Blades uses manual painting, while some other blade factories use robotized painting processes, which may lead to more even paint application.

Based on the observations made during the 12-13 February 2015 visit, as well as previous visits made by DNV GL to this facility, DNV GL considers the quality of the blades produced by Acciona Blades to be consistent with industry standard.

2.3.3.3 Blade manufacturing, TPI Wind Blade Dafeng Co., China

TPI, initially in the fiberglass boat manufacturing industry, started producing wind turbine blades in 2001, and currently has seven production facilities: three in the U.S., one in Mexico, one in Turkey, and two in China. TPI has manufactured blades for at least three other major turbine manufacturers. The Acciona blades manufactured by TPI will be an Acciona design “built-to-print” in the TPI facility in Dafeng, China, which is located approximately 300 km northwest of Shanghai.

DNV GL has previous experience with TPI, and considers them a top-tier third-party blade manufacturer with significant in-house knowledge of blade design, fabrication, processes, and tooling. Overall, the approach taken by Acciona in its outsourcing to TPI Dafeng appears reasonable. No specific risk elements are identified with respect to Acciona’s specifications and processes for outsourcing production of AW3000 blades to TPI China. The Acciona Supplier Quality Engineering (SQE) team periodically audits the quality system at TPI Dafeng. Acciona SQE team has performed three audits of the TPI quality system in 2014.

DNV GL visited the TPI Dafeng facility in November 2014, with follow-up visits in late January and early February 2015. The TPI Dafeng factory has 35,000 m^2 of floor space. As of DNV GL visit, only the

AW116/3000 (56.7 m) blade was being produced in this factory. TPI Dafeng is a recent addition for TPI: construction of the factory began in December 2013, and its first blade was produced in April-May, 2014. Current staffing is 450 persons, with 350 production workers, 35 quality personnel and the rest administrative staff. Average production rate was 12 blades per week on three production lines, with planned ramp-up to 15 blades per week. The factory was operating two shifts per day, seven days per week.

Overall the facilities, equipment, quality assurance/quality control system, and blade manufacturing processes at TPI Dafeng were found to be consistent with industry norms. Automated processes include fabric cutting, root cutting/drilling, and mixing of resin and adhesive. The main workshops were found to be clean and well-organized, with acceptable dust levels. The traceability in witnessed work procedure from incoming materials tests, acceptance criteria, test methods, and calibration of tools or equipment were all acceptable. All production documentation checked was found to be complete and correct.

The current quality system in use at TPI Dafeng is a copy of the quality system from TPI Taichung (China). TPI Taichung has been operating for approximately 6 years. The quality system includes a quality manual, procedures, working instructions, and records. The quality system in TPI Dafeng has been used operationally for about 6 months. Because TPI Dafeng is still in early production stage, the facility is currently not ISO 9001 certified. Acciona has confirmed that ISO 9001, ISO 14001, and OHSAS 18001 certification is currently in progress at TPI Dafeng and is expected by September 2015.

During the visits, DNV GL observed that at least one Acciona employee was present at the TPI Dafeng facility. Acciona later confirmed that it has two full-time employees stationed at the TPI Dafeng facility. Their main responsibilities include reviewing a percentage of bonding lines with UT (following the 100% checks performed by TPI), visual inspection of 100% of all bonding lines, finishing inspections on all blades, and quality control on TPI documentation. DNV GL sees Acciona’s presence at the TPI facility to be beneficial.

Overall, the DNV GL evaluation and follow-up surveys of blade manufacturing at TPI Dafeng were positive. While minor findings were opened during the first visit in November 2014, these items were satisfactorily closed during the follow-up visits, and no new findings were opened, with the exception of the outstanding ISO certification. Based on the observations made during the November 2014 visit and early 2015 follow-up visits, as well as DNV GL general knowledge of TPI, DNV GL considers the quality of the Acciona blades produced by TPI Dafeng to be consistent with industry standard, although it is recommended to follow-up with Acciona/TPI to ensure that the TPI Dafeng facility obtains its ISO 9001 certification in September 2015, as planned.

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 Acciona turbines) or subcontracted to third parties under warranty. Since then, AWP has established its own service department, independent of Acciona Energy. DNV GL 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. Acciona’s O&M strategy may vary from region to region. When servicing larger projects in regions with an established presence, Acciona typically places a site manager on each site, while service technicians may be subcontracted. In less mature markets, Acciona will generally have more Acciona technicians performing O&M, in order to ensure that Acciona’s quality requirements are met.

DNV GL has inspected Acciona turbines in Europe and the United States (U.S.), in addition to other turbine brands serviced by Acciona Energy in Spain. DNV GL 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, 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 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 GL 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 GL considers Acciona’s capabilities for remote monitoring to represent good industry practice, and considers Acciona’s redundancy capabilities to create a secure environment for projects, in case of catastrophe at one of the control centers.

3 TURBINE TECHNOLOGY DESCRIPTION

3.1 Overview

The Acciona AW3000 turbine platform includes four current turbine versions: the AW100/3000, 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.

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.

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. In total, Acciona has 15 design certificates (covering 34 WTG variants including 50/60 Hz and standard/cold temperature) and 15 type certificates for various versions of the AW3000 platform. Not all combinations of rotor diameter, hub height and frequency are certified, so certification status should be reviewed on a project basis depending on which turbine combination is to be supplied.

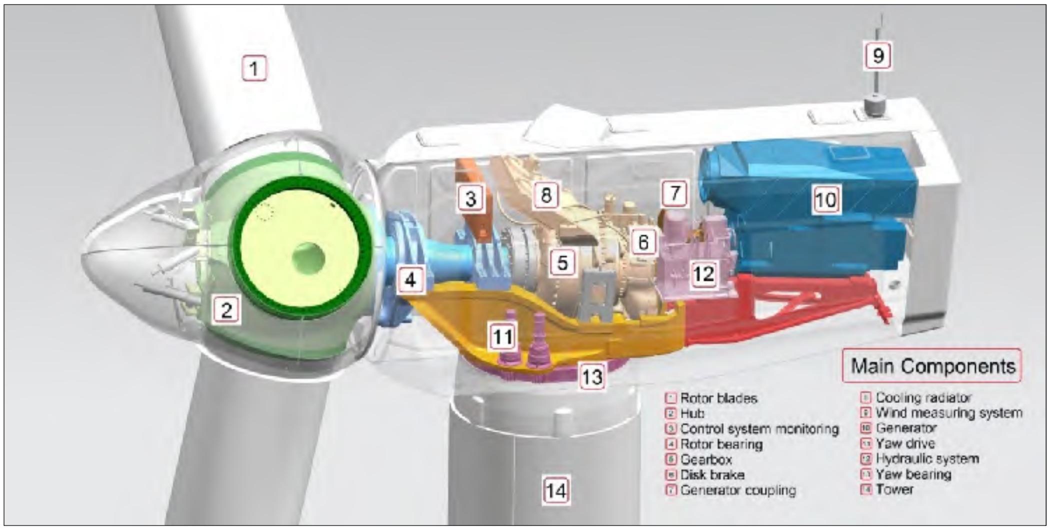


Figure 3-1 Cutaway of the AW3000

Table 3-1 Summary description of the AW3000 turbine

Item	**AW100/3000**	**AW116/3000**	**AW125/3000**	**AW132/3000**
Hub height(s) [1] [m]	100 (concrete)	92 (steel), 100 and 120 (concrete)	87.5 (steel), 100, 120, and 137.5 (concrete)	84 (steel) 120 (concrete)
Rotor diameter [m]	100	116	125	132
Rated power [kW]	3,000			
IEC design wind class	IA	IIA	IIB/IIIA/IIIB	IIIB
IEC classification edition	Ed. 2 (1999)			
V_{avg} [m/s]	10.0	8.5	8.5/7.5/7.5	7.5
V_{ref} [m/s]	50	42.5	42.5 / 37.5 / 37.5	37.5
V_{e50} [m/s]	70.0	59.5	59.5 / 52.5 / 52.5	52.5
Turbulence [%]	I_{15} = 18	I_{15} = 18	I_{15} = 16/18/16	I_{15} = 16
Shear exponent	0.20			
Air density [kg/m^3]	1.225			
Certification status	Type certificate GL: TC-GL-013A-2012, dated 23 Oct. 2012, expired Oct 2014	Type certificate: DEWI-OCC, TC-130602, Rev. 1, IEC Class IIA, dated 19 Dec. 2013 (2)	Design certificate: DEWI-OCC, STC-141111, Rev. 0, dated 24 Nov 2014, IEC Class IIb, (2) (Also type cert for 50 Hz version)	Not yet certified [3]
Cut-in & Cut-out [m/s]	4-25	3 - 25	3 - 25	3 - 25
Rotor speed range [rpm]	9.9 – 16.7	9.2 – 15.6	9.2 – 15.6	6.6 – 12.5
Nominal tip speed [m/s]	N/A	80.3	86.5	80.1
Gearbox Ratio	N/A	1:83 (50 Hz)/1:100 (60 Hz)		1:104(50 Hz)/ 1:125(60 Hz)

Item	AW100/3000	AW116/3000	AW125/3000	AW132/3000
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
Blade type, structure, material	Fiberglass reinforced epoxy structural shell with full-length spar	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	5-section concrete (100 m)	4 or 5 sections cylindrical steel (92 m), 5-section concrete (100 m), 6-section concrete (120 m)	4-section cylindrical steel (87.5 m) 5-section concrete (100 m), 6-section concrete (120 m), 7-section concrete (137.5 m)	4-section cylindrical steel (84 m) 6-section concrete (120 m)
Transformer type & location	Padmount (outside) or inside bottom of tower [4]			
Condition monitoring system (standard & optional)	<u>Standard:</u> • Temperature: oil, air, bearing, windings • Oil: filter pressure standard Optional vibration monitoring available in gearbox and on other bearings			
Service hoist capacity	500 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.			

Source: Turbine design certificates and Acciona documentation [6]

1. Some combinations of rotor diameter and hub height may not be available in all markets.
2. Other certificates also available, for various hub heights and/or IEC classes.
3. Statement of compliance expected 3Q 2015.
4. 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 with 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 process is common to several other large turbine manufacturers. Design and manufacturing processes appear well-controlled.
Pitch system	Yes	Hydraulic, one of two industry standard designs
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.
Power conditioning	Yes, see comments	The use of a medium-voltage generator is unique to Acciona; Acciona 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, the use of reinforced concrete is still uncommon. However, Acciona has 80 concrete towers for AW3000 platform with varying rotor size and height (along with 81 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 AW100/3000 blades are supplied by LM, which is the largest third party supplier of blades to the wind turbine industry and has a strong track record for quality and reliability. The blade for the AW100/3000, the LM48.8P, is drawn from LM's standard blade models. It has been used by other manufacturers on similarly rated turbines. The blades are manufactured from glass and polyester. No carbon is used, which avoids issues associated with the generally lower availability of this material, as well as additional complexity related to quality control and lightning protection. As with all LM blades, the AW100/3000 blade design has been subjected to static testing, in accordance with relevant standards and with dynamic testing in line with LM policy and IEC 61400-23 standards.

The AW56.7 blade for the AW116/3000 turbine is made of fiberglass reinforced epoxy, using a structural shell with full-length spar cap structure. The spar caps are also made of fiberglass. The blade has two main shear webs, uses PVC and balsa wood cores for the structural shells, and a T-bolt style root connection. DNV GL considers this to be a typical design configuration that has been used by multiple other blade manufacturers; Acciona has used a similar design for the AW1500 blade. 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 GL has no basis to doubt that these were appropriately considered by Acciona, as confirmed by the turbine's type certificate, and consequently DNV GL does not consider the blade weight to pose a risk to the blade or turbine design.

The blade for the AW125/3000 (AW61.2_1 or AW61.2_2 for IEC IIIA/IIIB or IIB, respectively) and for the AW132/3000 (AW64.7), were also designed by Acciona 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, Acciona 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 mold would normally require between one and two months) and advantageous time-to-market.

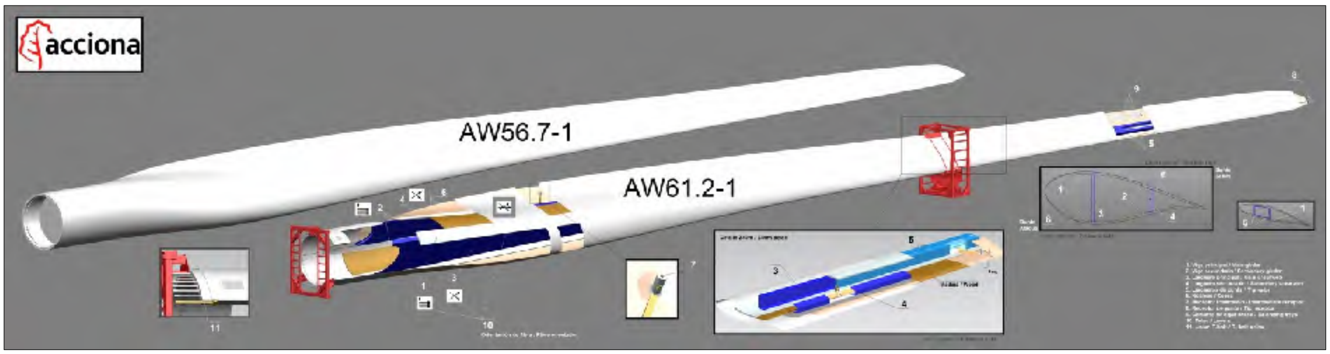


Figure 3-2 AW61.2-1 blade design

DNV GL reviewed both the Acciona blade design and manufacturing processes [6][7], including detailed discussions during a visit in June 2014: this design review was conducted in the Acciona engineering offices in Spain, and included presentations by Acciona, interviews with blade design engineers, and review of blade design and testing reports requested by DNV GL. 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), 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.

Acciona developed the blade design in partnership with We4ce from the Netherlands, as well as Garrad Hassan (now DNV GL) 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 GL also visited Acciona'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 or superior to the industry norm.

Acciona 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 structural robustness of the blade as well as validating structural analyses. Acciona also performed material and laminate testing at IMA (Germany) and WMC (Holland), where both standard and cold climate laminate testing has been done.

[1] This potential reduction in energy production is intrinsically included in each turbine's power curve.

The AW61.2_1 blade has the exact same structure as the AW56.7 blade for the first 43 m of the blade, which represents more than 70% of blade length[2]. Furthermore, because it is certified to a lower design class, the design loads for the AW61.2_1 are within the loads envelope of the AW56.7 blade. As such, 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.

Acciona 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 Assessment was obtained in September 2014. DNV GL reviewed this design development and finds it to be a minor change from the previously verified blade model.

The industry trend is to move to larger blades to expand the turbine's capabilities, but this trend has not been without risk. DNV GL 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 GL sees a low-to-moderate risk with large rotors until enough experience has been gained to demonstrate the stability of the new processes. However, it should be noted that this is a general risk area; no specific items of risk were identified in the review of Acciona blade design and manufacture. Acciona's practice of 100% ultrasonic bond line testing in all blades lends some comfort relative to the blade manufacturing risk.

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

3.2.1.1 Operational considerations

Throughout the wind industry, DNV GL has observed cases of blade damage due to resonant edgewise vibration in standstill conditions, herein called simply edgewise vibration, in various turbines with large rotors. 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 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 certification testing. To date, DNV GL is not aware of damage due to edgewise vibration in Acciona blades.

While having a relatively short operational history, the AW3000 is starting to build a track record, and Acciona advised that no damage due to edgewise vibration has occurred to date through its AW3000 fleet of turbines. Acciona 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 GL as a positive indication.

[2] 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.

Edgewise vibration is a low probability but high consequence event. As such, in general DNV GL 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 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 optimal operating conditions 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.

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 continuously, although this type of pitch control is not currently in use on the AW3000 turbines.

AWP has performed a workshop test of the pitch system. DNV GL was advised that the test was performed as a load test on the pitch actuation. The test can therefore be considered an endurance test of the pitch actuation system. DNV GL notes that the test is not an endurance test of the blade bearing, since no blade loads are applied to the blade bearing. However, DNV GL views the fact that AWP performs workshop tests on sub-systems as an indication of AWP's effort to improve reliability.

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 bearing, with the gearbox providing rear support. The main advantage of using two main bearings is that non-torque loading on the gearbox housing is minimized. Reduced loading means that there is less deflection of 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 dismantling the rotor.

Spherical roller main bearings have had substandard reliability in some other turbine manufacturers; however, DNV GL is not aware of main bearing problems in Acciona 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 in the AW3000 wind turbines.

Table 3-3 Summary of Gearbox Configuration, 50 and 60 Hz Turbines

	AW100/3000	AW116/3000	AW125/3000	AW132/3000
Suppliers & certified model number(s)	Moventas: PPLH-2900; Winergy PZAB 3535	Moventas: PPLH-2900.1 Winergy: PZAB 3535		Moventas and Winergy (model TBD[1])
No. of stages	3	3	3	3
Stage configuration	2 planetary stages, 1 parallel stage			
Gear ratio	1:92 (60 Hz) 1:77 (50 Hz)	1:100 (60 Hz) 1:83 (50 Hz)		1:125 (60 Hz) 1:104 (50 Hz)
Planetary bearing type(s)	Cylindrical roller bearings;			
Cooling configuration	Oil-to-air heat exchanger			

1 Expected to be similar to the gearboxes used in the AW116 and AW125, although the high-speed stage is expected to differ slightly.

The input stage is planetary and has four planet gears, contrary to the more commonly used three planet gears. DNV GL 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.

Acciona 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. Acciona advised that while both suppliers provide a viable solution, currently, Moventas is the preferred supplier of AW3000 gearboxes and most turbines in North America are to be equipped with Moventas gearboxes. As such, the following will mostly detail the Moventas "flex pin" design concept. More information will be needed for DNV GL to fully opine on the Winergy solution: ***for projects that will be supplied with Winergy gearboxes, DNV GL requests additional information related to the Winergy load sharing concept, validation testing and operational experience***.

Moventas' solution to the load sharing challenge includes mounting the planet gears on flexible pins which permits the planet gears to move circumferentially, 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 variability.

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 Acciona and Moventas, there are reportedly at least 600 wind turbine gearboxes with this technology currently in service with no known failures to report. DNV GL 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 GL considers the use of the flex pin technology in the first stage of the AW116/3000 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 HALT results, which show that the gearbox can withstand 20-year equivalent loading. DNV GL notes that this risk may be further mitigated by a project's warranty terms: for projects with a long warranty (five, or even better 10 years) DNV GL would expect that, should any issues related to the flex pin occur, Acciona and Moventas will complete a root cause analysis (RCA) and resolve the issue prior to the end of the warranty.

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 bearings 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 middle of 2016. DNV GL has not reviewed this gearbox in detail.

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 Acciona and has thereby enabled Acciona 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 GL reviewed test reports from HALT 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 HALT 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 HALT test. Results indicated good load distribution.

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

Acciona 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 run-in test, including monitoring for vibration and noise characteristics.

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 the generator configuration in the AW3000 wind turbines [10].

Table 3-4 Summary of generator configuration

Model	AW100/3000	AW116/3000	AW125/3000	AW132/3000
Generator rating [kW]	3,050			
Type	Wound Rotor DFIG			
Voltage [V]	12,000			
Generator suppliers & certified model number(s)	INDAR TAR630XA6 (50 Hz); INDAR TAR630XA6N60N (60 Hz); ABB [1] AML 630L6A BAFS (60 Hz)			Same suppliers expected, not yet certified
Frequency (of stator)	60 & 50 Hz			
No. of poles	6			
Rated speed	1,560 rpm (60 Hz) 1,300 rpm (50 Hz)			
Insulation class	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. Acciona 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 losses in the generator should be reduced relative to low voltage designs;
- For projects with 12 kV collection system, there is no need for step-up transformers at 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.

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 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.

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, 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 slew 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 geared motors. 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 84, 87.5 and 92 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 100 m, 120 m and 137.5 m, as discussed further below.

3.4.1 Concrete towers

The use of concrete towers is uncommon, although it is gaining popularity among manufacturers for the new generation of multi-megawatt turbines. AWP believes 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][12]. 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 GL 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 towers will be erected in the wind energy industry, as hub heights are increasing.

The Acciona concrete tower is made from pre-stressed 20 m precast shells that are assembled together on site, using Acciona's patented joints, to form 20 m concrete sections, as shown in Figure 3-3. 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 mortar joints. The completed towers are also post-tensioned using 6 tensioning cables located inside the tower. According to Acciona, the post-tensioning system is maintenance free [13]. Acciona further advised that their complete towers can be fully erected without a nacelle on top [12]. At the request of clients, the concrete towers can be painted, although paint is not required by design. DNV GL notes that while concrete can be designed to resist deterioration during its design service life, resistance to moisture or other chemical intrusion is important, and as such DNV GL recommends careful review of these aspects for any projects using concrete towers. 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.

Figure 3-3 AW3000 concrete tower segments

The Acciona concrete tower is an Acciona design, certified by DNV GL Renewables Certification. In addition to standard load calculations for fatigue and extreme loading, and the use of FEM analysis for the tower top interface, Acciona 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 Acciona, this test confirmed the results of the analytical loads calculations.

Acciona's first concrete tower was erected on a prototype AW1500 turbine in 2006. Since this first prototype, Acciona has gained additional experience with concrete towers on multiple projects, and as of Q2 2015, 85 AW1500 and 206 AW3000 turbines equipped with concrete towers are operational worldwide. Acciona's operational turbines on concrete towers include 80 m, 100 m and 120 m hub heights.

Acciona advised that a new, taller concrete tower, with a 137.5 m hub height, is currently in final stage of development. Acciona advised that the 137.5 m concrete tower option is currently commercially available in certain markets, and that it is expected to be certified by 4Q 2015.

Acciona Windpower can fabricate concrete towers themselves, capitalizing on their sister company Acciona Infrastructure, which has extensive experience with pre-cast concrete for bridges and tunnels. Acciona indicated that they have successfully sourced concrete tower materials locally for various international projects. Acciona's business model with concrete towers is oriented towards on-site manufacturing, including establishing a temporary concrete plant and a workshop where concrete shells are molded. In addition to potential 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.

DNV GL considers concrete towers to be a change from conventional steel towers, and as such, some risk remains until operational track record demonstrates the appropriateness of the design. Acciona is in the process of building this track record, with some turbines on concrete towers having been operational for more than 7 years (AW1500 turbines) and approximately 3 years (AW3000 commercial turbines; although the Peña Blanca prototype was installed on a concrete tower in 2008, and therefore has approximately 7 years of experience). Furthermore, the concrete tower type certification, along with the full-scale load test performed on a 100 m concrete tower, offers some degree of comfort.

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 [14] based on Siemens architecture.

DNV GL 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 GL has analyzed such data and can confirm that data coverage was reasonable, indicating satisfactory operation of the system.

DNV GL 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 Acciona 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

Acciona offers an optional condition monitoring system (CMS) [15], supplied by Mita-Teknik. Acciona 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 GL notes that the success of any condition monitoring system is directly related to the skills and experience employed in the data analysis. DNV GL does not have sufficient direct experience with Acciona’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]. Acciona advised that there have been no blade failures due to lightning that could not be repaired up-tower in the entire Acciona fleet of turbines, including both AW1500 and AW3000 turbine models.

Acciona 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. All major bearings include auto-lubrication as standard. The hub can be accessed without exiting the nacelle.

A lift is installed inside all tower types. DNV GL 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 crane with a capacity of 500 kg, sufficient to enable the replacement of minor components without the need for an external crane. Further, the nacelle cover was recently redesigned for improved ease of maintenance, including the ability to remove the top cover for lifting of heavy components with standard crane. 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 Temperature limits

Item	AW3000 Standard Version	AW3000 Cold Climate
Operational range [°C]	-20 [1] to +40	-30 to +40
Extreme range [°C]	-20 to +50	-40 to +50

1 The standard weather version currently has a certified operational temperature range of -10 to +40 with the exception of the AW116/3000 cold weather light version which has received a design certificate to operate down to -20 C, see below for details.

The AW3000 standard weather turbines have an operational temperature range that is certified from -10 to +40 with the exception of the AW116/3000 cold weather light version which has received a design certificate to operate down to -20 C. Acciona currently specifies an operational temperature range of -20 to +40 for all of the AW3000 platform. Acciona advised that all Acciona turbines, including AW1500 and AW3000 turbines, have been operated down to -20 for multiple years, which offers a good basis of operational experience. Acciona 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 GL generally recommend that the operational temperature range be confirmed by the certification agency, but based on the above, DNV GL considers the lack of certification of the -10 to -20 range for the standard weather version to present minimal risk for a project.

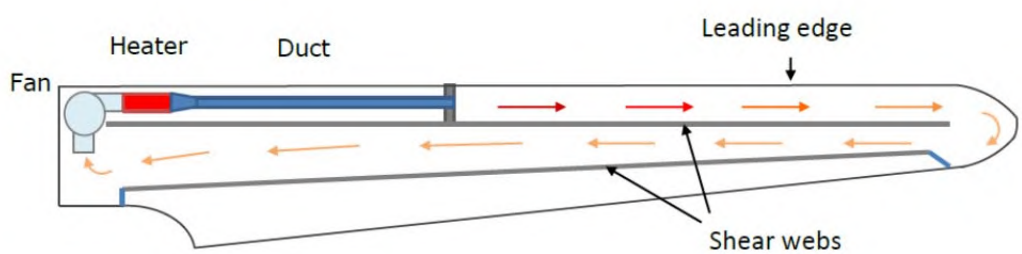
Many of the cold climate AW3000 turbine variants are certified, including the AW116/3000. These variants include the following modifications relative to the standard version [17]:

- 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: Heater resistances 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 using a frequency converter 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

Acciona is developing a blade de-icing system option for both the AW116 and AW125 turbine models. Preliminary technical specifications provided by Acciona [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 the AW116 and AW125. Acciona advised that prototype testing would be performed during the winter 2015-2016.

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



Source: Acciona [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 Acciona AW1500 turbine. Significant differences include larger rotors (most AW1500 turbines had 70, 77, or 82 m rotors, while the AW3000 has rotors of 100 m, 109 m, 116 m, 125 m or 132 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. Acciona 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. AWP currently owns 14 AW3000 wind turbines sited and available for testing and certification purposes.

It is of note that Acciona Energy is one of the largest owners and operators of wind turbines in the world, operating not only Acciona 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. As of the date of this report, 15 AW3000 variants have received a Type Certificate[3], 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, 15 AW3000 turbine configurations (covering 34 variants) 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 AW116/3000 and AW125/3000 certificates – Acciona advised that any new certificate would also reference the 2010 version of the GL guideline).

While DNV GL 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

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

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. Acciona indicated that they have considered load cases associated with edition 3. DNV GL has not reviewed Acciona's load analyses in detail.

4.2.1 German DIBt and grid compliance certification

Turbines to be installed in Germany are required to obtain both a German Type Approval and a Grid Unit Certificate. A German Type Approval consists of verification of the turbine loads calculated according to the Deutsches Institut für Bautechnik (DIBt) requirements, and an approval of the mechanical and electrical design for the nacelle and hub. German Type Approvals are issued by German authorities or authorized institutions. In general, a German Type Approval is comparable to a design certification according to IEC 61400-1. It should also be noted that the wind conditions according DIBt are based on wind zones (Germany is divided into different wind zones) and therefore the wind conditions covered by a DIBt approval are dependent on hub height. A further certificate confirming German grid compliance is issued following a grid unit test generally performed on a prototype.

Acciona advised that it will be pursuing DIBt certification for at least one turbine model: the AW125 low sound option with 137.5 m hub height. Grid unit testing will also be performed. According to a preliminary schedule provided by Acciona, the grid compliance test is to be performed between March and May 2015, with expectations to obtain a grid compliance certificate from DEWI OCC by the end of 4Q 2015. DIBt certification is expected to be obtained by 1Q 2016.

DNV GL sees no obstacles for Acciona to obtain the above mentioned DIBt certification and Grid Unit Certificate, although it is noted that this is Acciona's first time pursuing certification in Germany and as such DNV GL cannot comment on Acciona's timeline expectations.

4.3 Testing

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

Table 4-1 AW3000 testing status

Test	AW100/3000	AW109/3000	AW116/3000	AW125/3000	AW132/3000
Blade static & fatigue tests	LM Windpower	LM Windpower	CENER	CENER for the 61.2_1 and NaREC (UK) for the 61.2_2	CENER, iIn progress
Gearbox HALT tests	WINDTEST	WINDTEST	WINDTEST	WINDTEST	WINDTEST
Power curve tests	4Q2009 DEWI; DNV GL reviewed power curve test results for 50 Hz turbines only	1Q2011 DEWI; DNV GL reviewed power curve test results for 50 Hz turbines only	4Q2013 DEWI; DNV GL reviewed power curve test results for 50 Hz turbines only	1Q2015 DEWI; DNV GL reviewed power curve test results for 50 Hz turbine only	TBD
Loads validation	Date and agency TBD. Required and completed as part of type certification				TBD
Noise tests	1Q2009 DEWI (50 Hz only)	1Q2011 DEWI (50 Hz only)	4Q2012 DEWI (50 Hz); 3Q2013 DNV GL (60 Hz)	Completed Q2 2015 (50 Hz only)	TBD
LVRT, ZVRT tests	CIRCE	CIRCE	CIRCE	CIRCE	CIRCE
Power quality tests	3Q2009 DEWI (50 Hz only)	4Q2010 DEWI (50 Hz only)	3Q2013 DNV GL (50 Hz); 4Q2013 DNV GL (60 Hz);	Completed Q1 2015 (50 Hz only)	TBD

In addition to the tests above, AWP reports performing the following test 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: HALT test and static extreme test until breakdown
- Yaw brakes: Functional sword 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 GL 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 Acciona [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 Acciona document DG200032)
Voltage tolerance	Range 12 kV ±10%
LVRT (and ZVRT)	Capable (refer to Acciona 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 Acciona for the AW3000 turbines are presented in Figure 4-1.

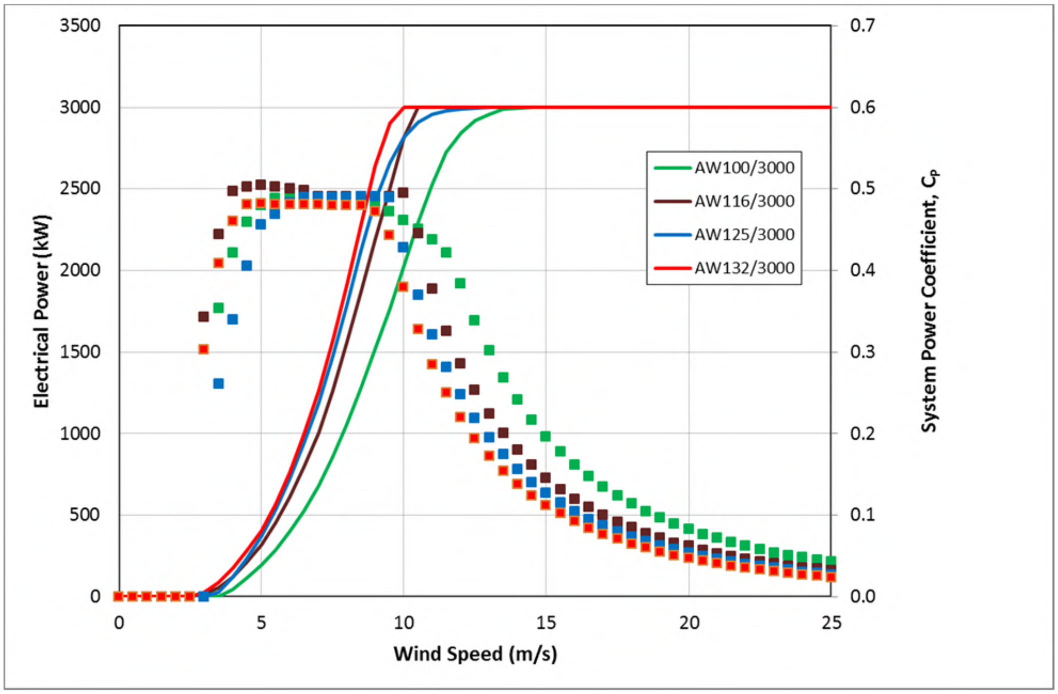


Figure 4-1 AW3000 sales power curve

As seen in Figure 4-1, the AW3000 turbines appear to have good performance as shown by the high C_p values, in the order of 0.5 for a wide range of wind speeds; that said, DNV GL notes that these C_p values provided by Acciona are steady calculated and do not account for mechanical or electrical losses in the turbine. DNV GL has used the sales power curves provided and calculated C_p values that include these losses: peak C_p values of about 0.47 were calculated, which would position Acciona's C_p values on, or slightly above, industry average.

4.5.2 Power curve verification

DNV GL has reviewed a total of eight power curve measurement reports for three variants of the AW3000 turbines. Seven of the eight 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 GL for review. Results for the power performance tests are shown below in Table 4-3.

Table 4-3 Summary table of power performance test results – AW3000 wind turbine

Test No.	Test location	Testing entity	Turbine model	Mean Wiebull Wind speed	Test procedure deviations from IEC standard	Results compared to sales power curve [1]	Test uncertainty	Turbine model capable of meeting power curve
1	Spain	DEWI	AW100/3000 IEC Ia TH100 50 Hz	8.5 m/s	Yes, minor	0 to -1%	±5%	Yes
2	Spain	DEWI	AW109/3000 IEC IIa TH100 50 Hz	8.5 m/s	No	0 to -1%	±6%	Yes
3	Spain	DEWI	AW109/3000 IEC IIa TH100 50 Hz	8.5 m/s	Not reported	~+0.2%	Not reported	Yes, incomplete information
4	Spain	Cener	AW116/3000 IEC IIa TH120 50 Hz (Rev A)	8.5 m/s	No	0.6 to -0.5%	±9%	Yes
5	Spain	DEWI	AW116/3000 IEC IIa TH120 50 Hz (Rev D)	8.5 m/s	No	0 to -0.3%	±6%	Yes
6	Spain	DEWI	AW116/3000 IEC IIa TH120 50 Hz (Rev F)	8.5 m/s	No	~-1%	±8%	Yes
7	Chile	DEWI	AW116/3000 IEC IIa T92 50 Hz	8.5 m/s	Yes, moderate	0 to -1%	Not reported	Yes, Incomplete information
8	Spain	DEWI	AW125/3000 IEC IIIa TH120 50 Hz	7.5 m/s	No	0 to -0.5%	±6%	Yes

1 Negative indicates underperformance. Figures may vary based on reference curve.

DNV GL notes that no power curve test results are available for the 60 Hz variants of the AW3000 turbines. IEC guidelines do not require a power curve test for different grid frequencies, and because the rated rotor speed of the AW3000 50 and 60 Hz turbines are the same, a 50 Hz test is likely to be applicable to a 60 Hz installation.

DNV GL considers that these tests demonstrate that the AW3000 turbines are capable of performing to the sales power curve within the test margin of error. That said, power performance is sensitive to site conditions and this should be accounted for in the energy assessments. While these test results show that the AW3000 are capable of meeting their sales power curves, until further independent verification has been completed for the AW3000 turbines in various site conditions and in 60 Hz, DNV GL 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 60 Hz power curve test for a project, and/or through an adequate power curve warranty.

4.5.3 Turbine sound power level

The highest mean apparent sound power level (Lwa) of the AW116/3000 is 106.6 dB(A), for the AW125/3000 it is 108.4 dB(A) and for the AW132/3000 it is 107.1 dB(A) [25], [26].

AWP advised that it is developing an AW125/3000 low sound turbine variant for 50 Hz markets, with a slower rotational speed and a sound profile that is approximately 2 dB less than the standard AW125/3000, thus implying a sound power level of 106.4 dB(A). Additional noise reduced operation modes may also be available to optimize the sound profile specific to project requirements.

DNV GL has reviewed high-level summaries of two sound power level measurement reports for the AW116/3000 wind turbine [27]. 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) [28].

Based on the above, and additional acoustic tests for the AW116, AWP has calculated a declared Sound Power Level (Lwd) which allows for the calculation of a 95% confidence level on the sound power.

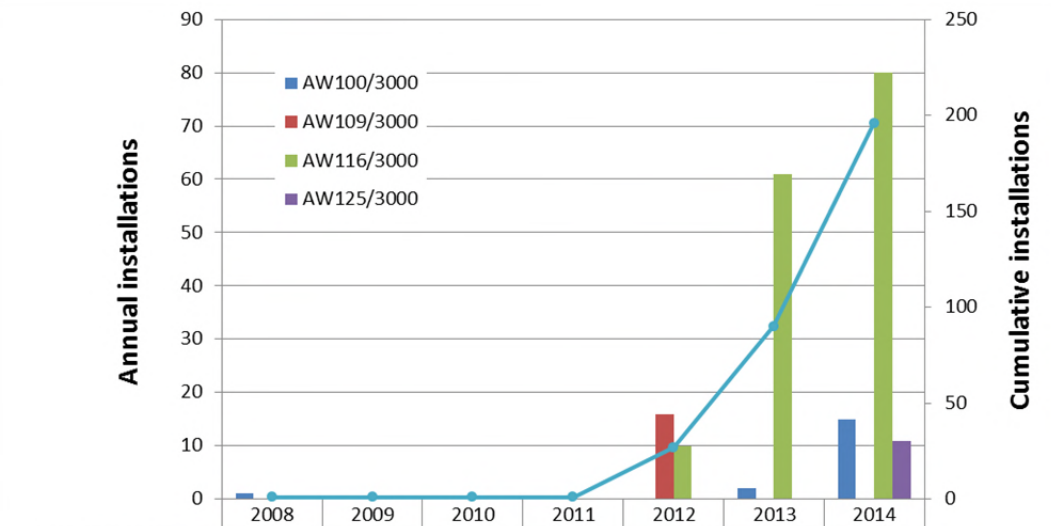
DNV GL also reviewed three additional sound power level test reports for the 50 Hz variants of the AW3000 platform: one for the AW100/3000, one for the AW109/3000, and one for the AW125/3000. The AW100 and AW109 tests were performed by DEWI in Spain and measurement results showed that the turbine is capable of meeting its specified sound power level [29]. 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 [30]. Based on the above, DNV GL considers that in general, the AW3000 turbines should be able to respect their specified maximum sound power level. DNV GL 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

4.6.1 Installation history

A relatively recent market entrant, the AW3000 platform has somewhat limited installations to date, with more than 220 turbine-years of global experience through Q2 2015. 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 Q2 2015, Acciona had 357 AW3000 turbines installed worldwide. In the first half of 2015, 161 AW3000 turbines were installed, including 31 AW100/3000, 92 AW116/3000, and 38 AW125/3000.

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.



	2008	2009	2010	2011	2012	2013	2014
AW100/3000	1					2	15
AW109/3000					16		
AW116/3000					10	61	80
AW125/3000							11
Cumulative AW3000	1	1	1	1	27	90	196

Figure 4-2 Worldwide installation history of AW3000 turbines (number of units installed)

With the limited track record of the AW3000 turbine platform, DNV GL also reviewed the history and known issues of the previous Acciona model – the AW1500 platform – to help understand future AW3000 turbine performance. Both platforms use similar turbine design concepts, as well as manufacturing and supply chain strategies. As of Q2 2015, 2,693 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 multiple other countries including significant installations in the U.S. and Canada, Latin America, Australia, and China.

4.6.2 Known technical issues

Acciona has provided DNV GL with information about several design changes that have been made as a result of its operational experience [32].

A turbine supplier's root cause analysis process is an indication of the supplier's diligence in addressing issues as they inevitably arise. Acciona 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 certain examples (including the gearbox issue described in Section 4.6.2.1), DNV GL finds that AWP has used a formal analysis process when major issues arise.

As examples of the Company's response to technical issues, a few instances are briefly outlined below.

4.6.2.1 Blade bearing issue, AW3000

DNV GL has been made aware by Acciona of a blade bearing issue that was recently discovered in the fleet. According to Acciona, the issue was first observed at an operational wind farm in March 2015, and an RCA was initiated by Acciona in April 2015. Acciona advised that the RCA is ongoing, with finalized results expected in 3Q 2015.

Acciona has contracted DNV GL Certification in Europe to audit the RCA process and provide technical guidance for the blade bearing issue. Acciona has proactively begun a campaign to reinforce turbine bearings for all operating and under construction AW116 and AW125 turbines. Acciona has conducted FEM analysis on the retrofit and has concluded that the retrofit will protect the bearings from excessive loads.

Acciona is working with their suppliers to revise the bearings and some initial changes have been made to the bearing design to address a suspected root cause. A potential root cause is the size of the ball entrance for the bearing, and the revised design includes a smaller ball entrance and a thicker external diameter. DNV GL Certification is working with Acciona to confirm that the required calculations and analysis are performed by Acciona in the design of the blade bearings.

DNV GL requests to review the RCA and corrective measures relating to the blade bearing issue, when available. DNV GL recommends that once available, the RCA's remediation measures, if needed, be appropriately implemented at all AW3000 Projects.

4.6.2.2 Gearbox failure and debris found in gearboxes, AW109/3000

Acciona advised that one AW3000 gearbox failure has occurred to date in the fleet of AW3000 turbines. Acciona completed an RCA with the gearbox manufacturer Moventas, a high-level overview of which was provided to DNV GL [33]; DNV GL considers this report as a good illustration of the 8D process being applied by Acciona and its supplier Moventas. Two root causes were identified by the RCA: missing axial clearance on the low-speed side and insufficient lubrication of some of the bearings. In total, 10 gearboxes were identified as potentially being affected by this issue, many of which were found with significant metal debris inside the gearbox, but only one failure occurred: the other nine were retrofitted on site prior to failure. Following the RCA, modifications to gearbox design were made by Moventas, and Acciona advised that as of end of February 2014, no other gearbox issues have been reported.

Acciona also advised that the Winergy gearboxes were not affected by this issue.

4.6.2.3 Lightning protection system modification, AW116/3000

Acciona indicates that during the installation of the first prototype of the AW56.7-1 blades, after a lightning strike, it was found that the LPS was broken. Down-conductor cables were found to be excessively tight and the connector was damaged. The design of the lightning system was checked with the conclusion was that it could lead to a risk of breaking the main cable due to an excessively tight connections. Acciona indicated that they modified the design of connections and location of the conductive cable of the lightning protection system in the blades to allow more flexibility in the conductor.

With the assessment of the company Global Lightning Protection Systems A/S (GLPS) a new system was developed, with the following improvements:

- 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 but GLPS noticed that the design could be improved. In the new design, the inner part of the receptors is electrically isolated in order to ensure that only the lightning will be collected in the external part.

4.6.2.4 Generator Stators, AW1500 turbines

In AW1500 turbines, a small percentage of INDAR generators failed due to the detachment of the magnetic wedges. DNV was contracted to analyze the stator production process of the INDAR generators. As a result, AWP implemented changes to the generator stator production process, including the curing process and slot filling method. For the AW3000 generators, production processes were changed to modify the slot filling configuration, modifying the curing process after stator impregnation, and magnetic wedges were eliminated and replaced with composite wedges.

4.6.2.5 Concrete tower

In October 2009 in Spain, a prototype AW77/1500 turbine on a concrete tower suffered catastrophic failure, causing the third concrete tower section, nacelle, and rotor to fall to the ground. AWP advised that an RCA has been completed, following which the concrete towers have been re-designed. While DNV GL has not reviewed the details of the RCA, it is noted that Acciona now has a significant number of concrete towers that have been installed for up to seven years (AW1500). DNV GL notes that this issue is only relevant to turbines on concrete towers, and recommends that details of the concrete tower be reviewed for any project that plans to use such towers.

4.6.2.6 Component reliability data, AW1500 turbines

While not directly relevant to the AW3000 turbines, reliability data for the AW1500 fleet of turbines is a good indication of Acciona's O&M capabilities. Given the similarities in design concepts between the two platforms, the good reliability history of the AW1500 fleet suggests that the AW3000 fleet may also be reliable, although only additional operational track record with the AW3000 will allow confirmation of this.

Acciona provided updated failures rates for the AW1500 global fleet of turbines in March 2015, as shown in Figure 4-3. While DNV GL has not independently reviewed these data, these numbers indicate that did Acciona succeed in keeping failure rates as low as in the 2007-2008-2009 era, and failure rates have improved compared to early-model years figures.

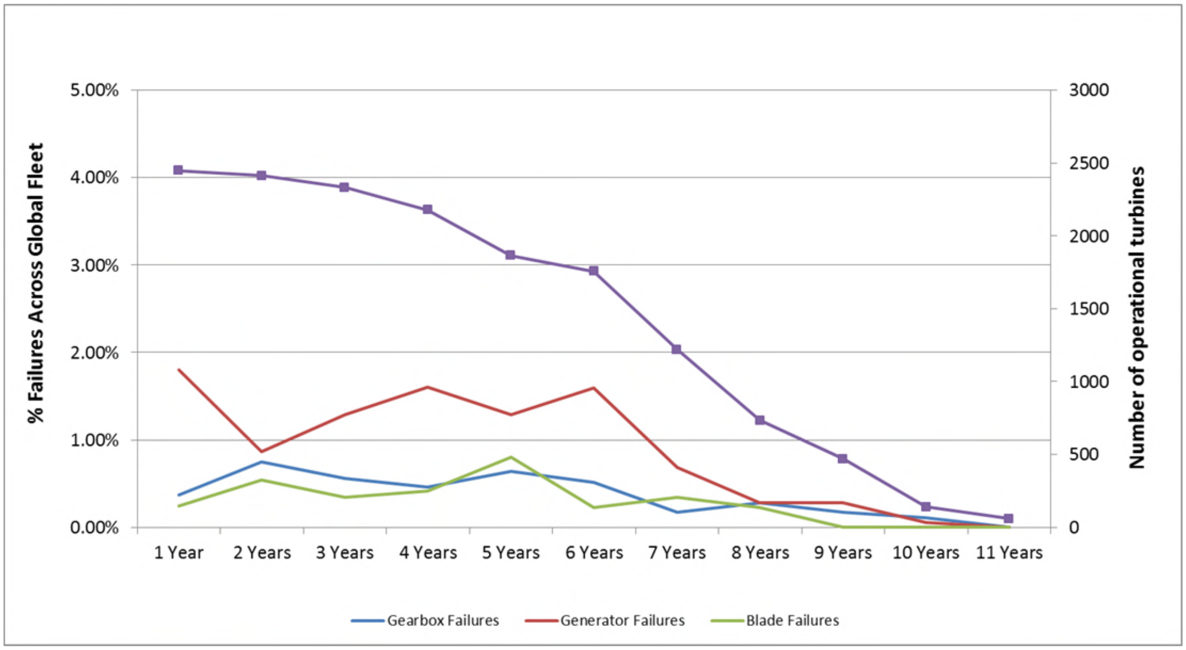


Figure 4-3 Percentage of major component failures across global AW1500 fleet

4.6.3 Historical performance and availability

DNV GL has independently reviewed the availability of the North American AW1500 fleet[4], but not the AW3000 fleet. Acciona has provided data for the AW3000 turbines in operation through 1Q 2015 which suggest that the AW3000 turbines are operating in line with industry standards.

In April 2014, Acciona provided the availability levels to date for its two largest 3 MW European projects (total of 27 turbines). The information provided by Acciona indicated that both projects have operated at availability levels between 93% and 94.5% on average since COD, using an availability definition similar to DNV GL wind-in-limits technical availability definition. Similarly to other projects in the industry, both projects have seen lower availability levels in the first few months after COD, such that an average availability of 95% is met if the first 3 months of data following COD are discarded (as is standard DNV GL practice). This is an indication that the turbine platform can operate at industry standard availability levels. Additionally, Acciona has provided to DNV GL general fleet-wide information on major component issues to date (as of 31 December 2014), which includes one gearbox replacement, one generator replacement and a hydraulic coupling retrofit; such events are not unexpected for a new turbine platform. Acciona also provided DNV GL with data and information about the worldwide fleet of the AW3000 turbine, including

[4] The review resulted in a fleet average of 97.1% for all commercial turbines operating in North America for at least a year post-commissioning, over a one-year period in 2012-2013. Note that there are many definitions of availability, each suitable for its own purpose. For the purposes of evaluating technology across all turbine models, DNV GL uses a uniform definition of availability that is designed to be compatible with the calculation of production estimates. This "wind-in-limits" technical turbine availability is in the form of a loss factor and is calculated as follows:

$$\frac{\text{(Total time producing kW)}}{\text{(Total time that the wind is between cut-in and cut-out, and absence of grid-out or BoP issues)}}$$

This "wind-in-limits" definition results in different values than the definitions often used for warranties, and therefore DNV GL's availability projections cannot be directly compared with warranted availabilities.

availability data up to 31 December 2014. Finally Acciona advised that there have been no blade issues to date on the AW3000 turbine fleet.

4.7 DNV GL Opinion: design status and projected availability

DNV GL considers a turbine to be *commercially proven* [31] 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.

Acciona has well-established engineering, manufacturing, and field service capabilities. Based on DNV GL's knowledge of Acciona, as well as Acciona's track record in North America with the AW1500 turbine platform, DNV GL considers that the first two criteria above are met in North America. Additionally, the AW100/3000, AW109/3000, AW116/3000 and AW125/3000 turbines within the AW3000 platform have obtained a type certificate; a type certificate requires both a design statement of compliance, as well as additional testing and manufacturing quality review, and as such, the third criterion above is considered to be fully achieved.

With regard to the fourth criterion, there are currently 96 AW116/3000 wind turbines operating in North America, with two wind projects commissioned in the first half of 2015. As such, the track record criterion has not yet been met in North America.

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.[5] DNV GL 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 GL considers the turbine to be moving towards becoming commercially proven.

With more than 125 turbine-years of experience worldwide as of 31 December 2014, and based on the availability data reviewed and Acciona's demonstrated experience with operations of turbines in North America (based on the AW1500 fleet of turbines), DNV GL considers the AW100/3000, AW109/3000 and AW116/3000 turbines to be qualified in North America. Furthermore, DNV GL does not see obstacles to these AW116/3000 turbines progressing to proven status as the turbines gain experience.

DNV GL may also consider these turbines to be qualified in other regions or countries where Acciona has well-established and demonstrated O&M and service capabilities. With a significant installed base and headquarters located in Spain, DNV GL can consider the AW100, AW109 and AW116/3000 turbines to be

5 See DNV GL's position paper on turbine reliability for types of experience needed to reach "qualified" status and for more discussion of this subject [31].

qualified in Spain. Status for other countries or regions may be reviewed by DNV GL on a project-specific basis.

Based on the significantly larger rotor size, DNV GL considers the AW125/3000 and AW132/3000 turbines to be different from the other AW3000 turbines and thus considers them separately. Based on Acciona's reported order book for the AW125/3000, and assuming that the AW125/3000 turbines reach similar availability levels as the AW3000 with smaller rotors, DNV GL considers that the AW125/3000 could become qualified in North America by the end of 2016. DNV GL sees no obstacles for the AW125/3000 and AW132/3000 to proceed and mature as many of the other turbine models have done in the industry, and progress to *qualified* and then to *proven* status as the turbine gains experience.

DNV GL recommends assuming a one year ramp-up in availability after commissioning, with nominal technical turbine availability of 96% being achieved for the Acciona 3.0 MW turbines, 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 three to five, 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.

4.8 Expected operating life

The typical design operating life of a wind turbine is 20 years, as suggested in the IEC 61400-1 design standard. Based on the type certification obtained for multiple variants, DNV GL 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:

- As a turbine manufacturer, Acciona Windpower (AWP), a subsidiary of the Spanish infrastructure conglomerate Acciona S.A., has significant turbine installation experience, mostly from the AW1500 platform, in multiple countries including Europe, Latin America, China, Australia, U.S., and Canada.
- Acciona Energy, another subsidiary of Acciona S.A., is one of the largest owners and operators of wind turbines in the world, operating not only Acciona 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 and 64.7 m through Acciona Blades) and concrete towers (through Acciona Infrastructure), and assembly is performed for nacelles and hubs. Blades may also be supplied from LM Wind Power (100 m rotor) or built-to-print by TPI in China or Aeris or Tecsis in Brazil. AWP subcontracts all other manufacturing.
- The AW3000 turbine design is relatively conventional, with the exception of the 12 kV generator, which Acciona 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 a type certificate, including the cold weather package as well as the AW116/3000 and AW125/3000. The AW132/3000 has not yet obtained Design Assessment or Type Certification.
- Based on the significantly larger rotor size and doubled power rating, DNV GL considers the AW3000 turbines to be sufficiently different from the AW1500 turbines that its design and availability projection should be considered separately, although Acciona's experience with the AW1500 in specific markets, particularly North America and Spain, has demonstrated Acciona'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 GL sees the significant experience gained with this prototype as beneficial.
- The AW3000 platform has recently been introduced commercially to the market and as such, has somewhat limited installations to date, with slightly more than 220 turbine-years of global experience as of Q2 2015. The platform has seen a significant number of installations in 2014 and 2015.
- With more than 125 turbine-years of experience worldwide as of 31 December 2014, and based on the availability data reviewed and Acciona's demonstrated experience with operations of turbines in North America (based on the AW1500 fleet of turbines), DNV GL considers the AW100/3000, AW109/3000 and AW116/3000 turbines to be qualified in North America. Furthermore, DNV GL does not see obstacles to these turbines progressing to proven status as the turbines gain experience. Acciona has well-established engineering, manufacturing, and field service capabilities. As such, DNV GL would expect the AW3000 turbine platform to proceed and mature as many of the other turbine models have done in the industry, and progress to proven status as the turbine gains experience.
- DNV GL recommends assuming a one year ramp-up in availability after commissioning, with nominal technical turbine availability of 96% 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 five, with declining levels expected in subsequent years.

6 REFERENCES

	Reference	Document Classification
[1]	BTM Consult ApS, "World Market Update 2012," March 2013 and "World Market Update 2008," March 2009.	Published
[2]	Acciona Energy Market Report 2013 and confirmation by AWP on 20 March 2015.	Published
[3]	Acciona, "Acciona Windpower Global Track Record, Quarterly Report for Q4, 2014", Global Track Record_Q4_2014.pdf, not dated.	Confidential
[4]	Acciona Windpower, "Acciona Company Introduction", presented to DNV GL at the Barásoain facility on 11 February 2015.	Confidential
[5]	Acciona Windpower, "AW3000 Technical Description", Document DG178034, Rev. I, 02 April 2013	Confidential
[6]	Acciona Windpower, "61.2 Blade Structural Design Class IIIB , 50Hz/60Hz – 100 m Tower, Document DPIC009-AW61.2, Rev. A, 26 March 2014.	Confidential
[7]	Acciona Windpower, "61.2 Blade Structural Design Class IIIB , 50Hz/60Hz – 87.5 m steel Tower, Document DPIC008-AW61.2, Rev. C, 21 January 2014.	Confidential
[8]	Acciona Windpower, "Acciona Windpower TECHNOLOGY REVIEW DNV-GL", February 2015.	Confidential
[9]	Moventas, "FlexSpider Advanced load sharing system", 10 July 2014.	
[10]	Germanischer Lloyd, "Certification Report for ABB Generators Type AMI 630L6A BAFS, 60 Hz," Component Certification, Report 75068 Rev. 1, 6 May, 2014.	Confidential Confidential
[11]	Acciona Windpower, "ACCIONA Concrete Tower: industrial and global product The way to reduce the Cost Of Energy", Ivan Garcia Maestre, R&D&I Department, not dated.	Confidential
[12]	Acciona Windpower, "AW-3000 Concrete Towers", Acciona Concrete Tower_3_Industrialization.pdf, February 2015.	
[13]	Acciona Windpower, "CONCRETE TOWER", Acciona Concrete Tower_2.pdf, not dated.	Confidential
[14]	Acciona Windpower, "SCADA System General Description," Document DG200340, Rev. D, 29 April 2014.	Confidential
		Confidential
[15]	Acciona Windpower, "MITA-TEKNIK'S CMS DESCRIPTION (AW3000)", Document DG200298, Rev. B, 16 January 2013.	Confidential
[16]	Acciona, "AW3000 earthing and lightning protection systems", Document DG200233, rev. B, 23 September 2011.	Confidential
[17]	Acciona Windpower, "AW3000 Low Temperature," Document DG200281, Rev. A, 23 June 2011	Confidential
[18]	Acciona Windpower, "AW3000 De-icing system. Preliminary design and technical specifications.", Document IIP.0267., Rev. A, 25 March 2014.	Confidential
[19]	Acciona Windpower Presentation: AW3000 Testing not required for certification, by email to DNV GL on 19 June 2014.	Confidential
[20]	Acciona Windpower, "AW3000 Electric grid data," Document DG200032, Rev. G, 08 February 2012.	Confidential
[21]	DEWI, "Extract from Test Report DEWI S PV09-013.01", 11 September 2009.	Confidential
[22]	DEWI, "Extract from Test Report DEWI-SPA-PV10-00248-01.01", 08 February 2011.	Confidential

Reference		Document Classification
[23]	DEWI, "Extract from Test Report DEWI-SPA-PV13-00507-02.01", 20 December 2012.	Confidential
[24]	DEWI, "Extract from Test Report DEWI-SPA-PV14-00596-01.01", 23 January 2015.	Confidential
[25]	Acciona Windpower, "Sound Power Levels AW116/3000," Document DG200266, Rev. E, 05 March 2014.	Confidential
[26]	Acciona Windpower, "Sound Power Levels AW125/3000," Document DG200383, Rev. A, 23 November 2013.	Confidential
[27]	CENER, "Extract from Test Report 21.2679.0-PP-R", 12 March 2013.	Confidential
[28]	Germanischer Lloyd, "Extract from report for Acoustic test of AW116/3000 IEC IIA TH100 60 Hz at Pioneer Grove Wind Farm, Iowa, USA," 19 March 2013.	Confidential
[29]	CENER, "Extract from Test Report 21.2679.0AN Acoustic noise test for an AW116/3000", 20 November 2012.	Confidential
[30]	Agresse Engineering, "Summary of results of the noise emission measurement, in accordance with IEC 61400-11 ed. 2.1 of a WTG AW125/3000", 13 May 2015	
[31]	GL Garrad Hassan America, Memo: "Garrad Hassan America Position on Turbine Reliability Risk Assessment: Proven and Qualified Turbine Designs and Turbine Availability", 104776/AM/01, Issue A, 5 January 2011; URL: http://www.gl-garradhassan.com/assets/downloads/GL_Garrad_Hassan_memo_on_availability_and_proven_qualified_turbines.pdf.	Published
[32]	Acciona Windpower, "Engineering Changes in the Design of the AW-3000 Technology," Services Engineering Report, document number INF.IS.008.14, Rev. B., 2014.07.18.	Confidential
[33]	Acciona Windpower, "8D-REPORT Debris inside 3MW gearbox", FE01_IE09_PG0703 Rev01, Close date 6 June 2014.	Confidential

Rev	Fecha Date	Descripción de la revisión Description of the revision
"A"	30/09/14	Initial release
"B"	11/05/15	T84 wind turbine model added. Validity conditions updated.
"C"		
"D"		
"E"		

Realizado / Done	Revisado / Reviewed	Aprobado / Approved
08-05-2015	11-05-2015	11-05-2015

1. Introducción

Los niveles de Potencia Sonora Estimados (L_{wa}) se muestran para la turbina AW132/3000.

Estos valores de potencia sonora son válidos solo para las siguientes condiciones

- Tensión de red por debajo del +2.5% del valor nominal
- Generación de potencia reactiva y los algoritmos de control del parque desactivados
- Temperatura dentro del rango entre -20ºC y +40ºC
- Sin condiciones de hielo, esto es, temperatura mayor que +5ºC y humedad relativa menor del 80%
- Puertas de góndola y base de torre cerradas tanto para la turbina medida como todas aquellas que se encuentren a la vista.

Las velocidades de viento representadas están referidas a la altura de 10 metros sobre el nivel del suelo. Para extrapolar a otras velocidades a altura de buje se debe aplicar la IEC61400-11:2002 ed.2. Un valor típico de la longitud de rugosidad es 0.05m, aunque dicho valor depende del terreno concreto.

1. Introduction

Estimated Sound Power levels (L_{wa}) are provided for the AW132/3000 wind turbine.

These sound power levels are valid only for the following conditions:

- Grid voltage below +2.5% of nominal value
- Generation of reactive power and wind farm algorithms deactivated
- Temperature inside a range between -20ºC and +40ºC
- No iced conditions. Temperature above +5ºC and relative humidity below 80%
- Nacelle and ground doors closed for either measured wind turbine and everyone in sight

The represented wind speeds are referenced to a height of 10 meters above ground level. For the extrapolation to other hub height wind speed IEC 61400-11:2002 ed.2 has to be applied. A typical value of roughness length is 0.05m; however, it depends on the site terrain.

2. Niveles de Potencia Sonora

2. Sound Power Levels

Wind speed at 10m height (m/s)	6	7	8	9	10
Wind speed at 120m height (m/s) [z_0=0.05m]	8.8	10.3	11.8	13.2	14.7
Sound Power Level (dBA) TH120	**107.1**	**106.9**	**106.5**	**106.4**	**106.7**

Wind speed at 10m height (m/s)	6	7	8	9	10
Wind speed at 84m height (m/s) [z_0=0.05m]	8.4	9.8	11.2	12.6	14.0
Sound Power Level (dBA) T84	**107.1**	**106.9**	**106.5**	**106.4**	**106.7**

NOTA: Se asume una longitud de rugosidad de 0.05m para la extrapolación de la velocidad a altura de buje

NOTE: Roughness length of 0.05m is assumed to the hub height wind speed extrapolation

3. Nivel de Potencia Sonora Aparente Garantizado

El nivel máximo de potencia sonora aparente garantizado incluirá una tolerancia para tener en cuenta la incertidumbre de medida. La tolerancia es igual a la incertidumbre estándar combinada definida en la norma IEC 61400-11:2002 ed.2 y se aplica al nivel de potencia sonora reportado en la sección 1 *y* a los resultados del ensayo. Como valor de referencia, un valor típico de incertidumbre estándar combinada es ≤ 1dB.

3. Apparent Sound Power Level Guaranteed

The guaranteed max apparent sound power level will include a tolerance to account for measurement uncertainty. The tolerance is equal to the standard combined uncertainty defined in IEC 61400-11:2002 ed.2 and is applied to both the sound power level reported in section 1 *and* the test result. For reference purposes, a typical standard combined uncertainty is ≤ 1dB.

4. Tonalidad

Se puede suponer una audibilidad tonal de ΔL_a ≤ 2dB a lo largo de todo el rango operacional

4. Tonality

A tonal audibility of ΔL_a ≤ 2dB can be expected over the entire operational range.

5. Bandas de Octava

Solo a propósito informativo se muestran el espectro máximo de banda de octava esperado (no garantizado)

5. Octave Bands

Maximum expected octave band spectra are provided for informational purposes only (not guaranteed).

Octave Band (Hz)	32	63	125	250	500	1000	2000	4000	8000
L_{wa} (dBA)	73.6	84.7	96.7	102.4	101.6	98.1	96.5	94.5	87.9

Valores representativos de la velocidad de viento asociada al mayor nivel de potencia sonora

Values represented for the wind speed bin associated with the highest sound power level

EXHIBIT C

REVISED PROJECT LAYOUT

QUANTUM UTILITY GENERATION

EXHIBIT C

Revised Wind Turbine Siting Plan (2/3/16)

Site Permit Amendment Request

Flat Hill Windpark I, LLC

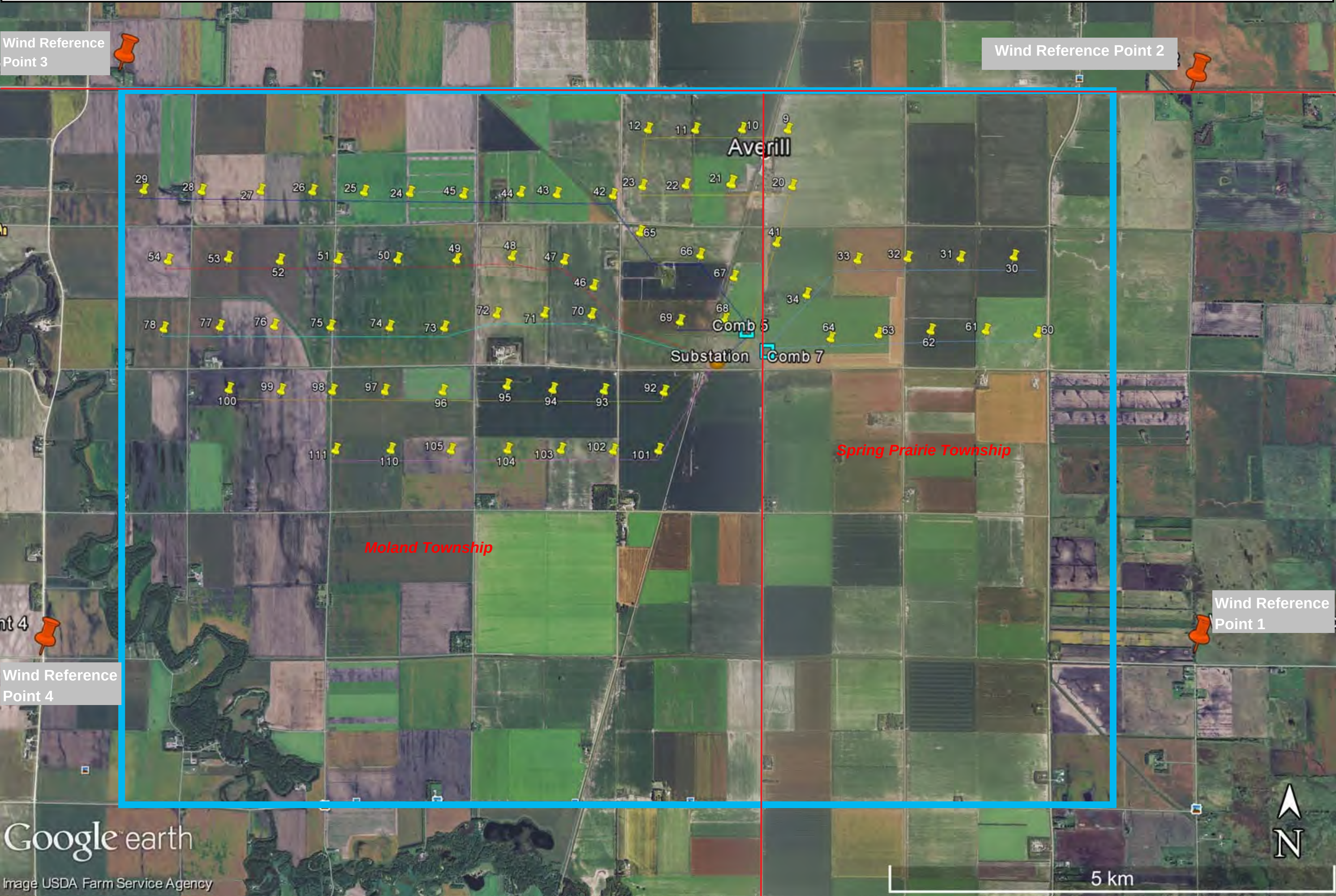
Permit Boundary

Township Boundary

Substation

Turbine Location

Meteorological Tower



STATE OF MINNESOTA
BEFORE THE
MINNESOTA PUBLIC UTILITIES COMMISSION

In the Matter of Flat Hill Windpark I, LLC's Site Permit for a 201 Megawatt Large Energy Conversion System and Associated Facilities in Clay County, Minnesota	)))))	Docket Nos. IP-6687/WS-08-1134 and IP-6687/CN-08-951 **CERTIFICATE OF SERVICE**

Catherine M. Wood, certifies that on February 3, 2016, she served true and correct copies of the **COMPLIANCE FILING AND SUPPLEMENT TO PETITION FOR MODIFICATION OR AMENDMENT TO THE SITE PERMIT OF FLAT HILL WINDPARK I, LLC** upon the following parties via e-filing and/or U.S. Mail:

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