The "Exclusively Offshore" Wind Turbine

Advancement and Testing of the Adwen M5000 Technology Under Severe Conditions at Sea

Gerrit Haake, Annette Hofmann, Copy edited by Björn Johnsen

© Springer-Verlag GmbH Germany 2017
M. Durstewitz, B. Lange (Eds.), *Sea – Wind – Power,* DOI 10.1007/978-3-662-53179-2_11

Project information: Innovative further development, construction and testing of the offshore wind turbine AREVA Wind M5000 under severe offshore condition in the offshore test field Borkum West
Project management:
Adwen GmbH
Joachim Arndt

11.1 Objectives

One of the two wind turbine types in the Alpha Ventus offshore test field is the Adwen AD 5-116 (previously: Multibrid M5000) with a power output of 5 megawatts (Fig. 11.1). Its prototype was initially also erected four times on land. But it is the first wind turbine developed exclusively for use in deep sea water.

The questions raised in connection with the research project on this wind turbine were therefore of great importance: how can the weight of the rotor blade be reduced to save costs? How can an even greater rotor diameter for even higher energy yields be developed in the future? This would require a larger crane and an appropriately dimensioned jack-up vessel.

And what about the components inside the turbine? Are converter and transformer correctly dimensioned? Are the established cooling systems adequate? What special protection systems are needed during deep-water operation to prevent salt accumulating inside the nacelle and damaging the components? What kind of electronic interfaces need to be developed to enable an exchange of data between wind turbines from different manufacturers within one wind farm? How can a helihoist platform be integrated into the structure to provide access to service technicians or for emergency responses by helicopter? And above all: what is the degree of wear to the compact drivetrain during deep-water operation? Do generators, gearboxes, bearings and rolling elements hold up to the promises of their manufacturers? Interim results were provided when, after four years of operation for testing purposes, the entire drivetrain of an Adwen wind turbine was removed, almost entirely taken apart and then comprehensively examined and analysed. The results confirmed the assumptions made up to now that aim for a service life of 20 years and longer.

Another special aspect of this project is that Adwen (formerly Multibrid GmbH) – unlike Senvion (formerly REpower) – also supplied and installed the foundation structures for their wind turbines in Alpha Ventus so that the wind turbines erected were handed over to the wind farm operator DOTI (Deutsche Offshore-Testfeld und Infrastruktur GmbH & Co. KG) in a "turnkey" condition.

11.2 Forward Sweep Instead of Bending Moments

The rotor blades played a key role in the research project "M5000 Advancement" (Figs. 11.2 and 11.3). The aim here was to develop a load-reduced rotor blade – which is what the subsidiary Adwen Blades did. Two development consultancies specialising in aeroelastic calculations for wind turbines were also involved. The conclusion reached: a greater forward sweep in the new blade design ensures greater aeroelastic stability. At the same time a change was made in the material used for the load-bearing elements of the rotor blade: glass-fibre-reinforced plastics (GRP) instead of the carbon fibres used up to then – which leads to considerable cost savings. The altered geometry of the rotor blade, its increased forward sweep, combined with the new GRP material means that the rotor blade can now be larger without significantly increasing the loads on the drivetrain and nacelle. Thanks to stringent development efforts it has therefore been possible to maintain the existing nacelle and drivetrain structures without significant changes in spite of the marked increase in the size of the rotor.

The increased size of the rotor diameter means that the wind turbine is activated even at lower wind speeds, gets up to its rated power more quickly and can therefore supply a lot more offshore wind power. A prototype with 135 metres rotor diameter was constructed on land in Bremerhaven-Lehe in 2013 and has been certified as AD 5-135.

Fig. 11.1 Nacelle AD 5-116 with rotor star and the Alpha Ventus wind farm in the background. The red structures on the nacelles are the winching platforms that enable personnel and material to be transported to and from the turbine. © Adwen/Jan Oelker

Fig. 11.2 Nacelle and rotor star of an Adwen AD 5-116 on an installation vessel ready for assembly. © Adwen/Jan Oelker

11.3 Learning Objective: Ruggedness

Before the wind power generated by the wind turbines could be transported to the consumers on land the generator voltage must be adjusted by the converter to 50 Hz and by the transformer to 33 kV. Prior to Alpha Ventus the state of technology was that the converter and transformer in some offshore wind turbine types are located in or below the nacelle in a special container (as in the 3.6 MW wind turbines in Arklow Bank in the Irish Sea) or down in the foot of the tower on a platform (as in the 1.5 W wind turbines in Utgrunden in the coastal waters of the Swedish Baltic). All these construction types were unsuitable for the M5000 technology because they are subject to different loads and methods of construction. Something new was needed. For the AD 5-116 in the North Sea there was the further stipulation that 90 % of the heat loss be discharged outside the tower to avoid overheating the components in the tower. The second major stipulation was that no fresh air should enter the tower for cooling purposes in order to avoid harmful deposits of salt and dust.

Fig. 11.3 A tower segment being raised from the installation vessel and onto the segment already in place where the service technicians are ready and waiting. Part of the 56.5-metre-long rotor blade can be seen in the foreground. © Adwen/Jan Oelker

11

Definition

- **Converter:** The converter's job is to adjust the variable frequency generator current of the wind turbine to the grid frequency.
- **Transformer:** The transformer is used to transform the voltage of a wind turbine generator to the voltage level of the internal wind farm cabling, e. g. from 1,000 to 33,000 volts (33 kV). At the offshore substation another transformer adjusts the voltage level to that of the high-voltage grid (110 kV) for the approximately 75-kilometre connecting cable from Alpha Ventus through the North Sea, over Norderney and through the Wattenmeer to the mainland.

These two stipulations and the dimensions of the tower made it necessary to develop a new and complex method of construction with liquid-cooled converters and transformers with integrated cooling plants. There was nothing like that on the market. In order to develop the converter for offshore operation the engineers changed the cooling pipework and enlarged the expansion tank to make the overall cooling system in itself more robust. Objective: greater ruggedness against the harsh environmental conditions at sea such as air pressure, temperature, humidity and salt.

The developers additionally doubled the chopper resistance to fulfil the grid connection requirements in case of power failure – plus an additional reserve of 80 % and implementation of corresponding control programmes in the wind turbine. For operation of the transformer at sea they reduced the size of the oil–air heat exchanger and changed the design accordingly.

» **Alpha Ventus has been an important milestone for us!**
Using the knowledge gained through Alpha Ventus the company has been able to move on to commercial offshore projects. This has resulted in 120 of our wind turbines in commercial operation in the North Sea today. We will continue this burgeoning development from 2015 onwards in the Adwen Joint Venture.
Luis Álvarez, CEO of Adwen GmbH in August 2015

They similarly established long-term monitoring of the converter and transformer with error–root cause analysis. Example: in the course of a failure of a semiconductor in the Alpha Ventus wind farm the error–root cause analysis showed that a connecting cable had been incorrectly fitted. As a result of this the assembly process was reviewed so that this error could not happen again. This systematic quality assurance enables errors to be identified at a very early stage and their cause to be swiftly remedied. These learning experiences led to the development of a full load test stand. The test stand went into service in 2011.

11.4 Before We Take to the High Seas: Testing

Adwen built a test stand in Bremerhaven for quality assurance and optimisation and additionally for the further development of converters and transformers (◘ Fig. 11.4). All wind turbines can be completely tested here with 5 MW full load or part load and, in particular, with all functions. Troubleshooting on the high seas is both time-consuming and expensive. The effects on the 20 kV grid and compliance with mains supply criteria are the key elements of the Adwen test stand. The full load test stand has been in full serial operation since 2012. In the course of the project another comparable test stand for wind turbines was built at the University of Hanover for 1–2 MW output. Adwen was able to share their knowledge in the planning and realisation of this test stand.

The full load test stand uses the "back-to-back" procedure (B2B). For this two wind turbines of the same type are mechanically and electrically connected (◘ Fig. 11.5). The Adwen test stand in Bremerhaven is additionally used for various tests and measurements outside the serial tests, for example for the verification of a generator cooling system, the exact measurement of all currents, voltages and outputs of the B2B test stand and also to check a condition monitoring system (CMS) that has been developed. Before it is erected at sea every completed wind turbine is subjected to a 27-hour endurance test, 12 hours of which is nonstop under full load.

11.5 Not Quite Like Your Living Room Yet: Climate Control in the Inner Tower

There were endless demands on the cooling systems for climate control in the interior of the tower – but nothing on the market at that time. Some solutions for a few individual demands were already available though.

Example: an air/water heat exchanger did not have to be invented – these systems are not new.

◘ **Fig. 11.4** Bird's-eye view of the Adwen test stand in Bremerhaven. © Adwen/Jan Oelker

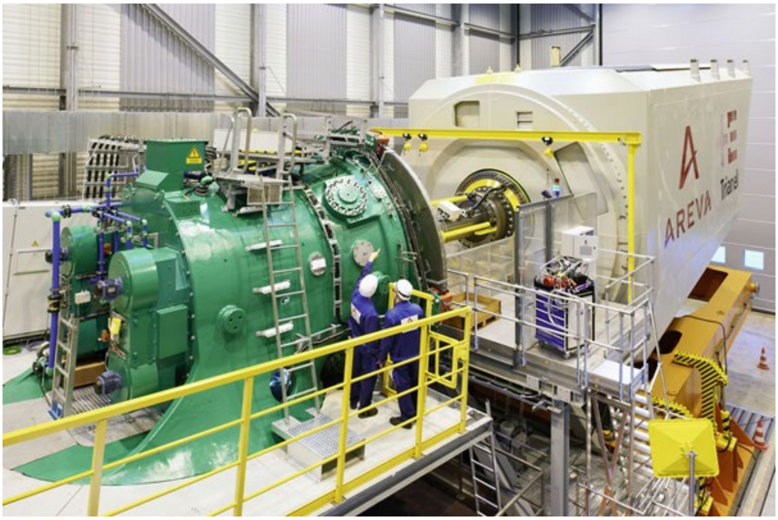

Fig. 11.5 Inside view of the Adwen test stand. © Adwen/Jan Oelker

However, a heat exchanger installed "outside" next to the tower had to be constructed in such a way as to ensure that it always had the same cooling characteristics. However strongly the wind howls outside or the outdoor temperatures rise or fall, the air/water heat exchanger must ensure that the temperature inside the tower is always the same. It must also be protected from corrosion by salt water and function for at least two years without maintenance. After all you can't send the service team out to sea every few weeks or months just because the climate control in the inner tower is not up to living room standards.

Similar applications on large oil rigs were only of limited assistance in designing this system: because there is more room on a rig than in a tower, the components are more easily accessible and the climate control expenditure much higher. And 24-hour monitoring by personnel is guaranteed on an offshore oil rig.

Conclusion: the cooling concept is known but needs new development before it can be used in an offshore wind turbine. What is more, the wind turbines stand on different foundations depending on the specific conditions of their location – and the cooling concepts therefore must be suitable for tower substructures both of steel and concrete. The decision was made to fit three or four air/water heat exchangers directly onto the tower to the right and left above the entrance door. An oil/air heat exchanger is also located in the tower: the cooling air is drawn in through vents in the tower door, led through ducts to the heat exchanger and then taken back through ducts to the tower door where it is released into the atmosphere.

The higher the altitude the lower the salt content of the air. By moving the air intake point of the tower from 15 metres to a height of 90 metres it is possible to reduce the salt content by 27 %. This leads to: a lower salt content, a lower filter load and therefore longer run times for the systems without servicing. A multistage filtration system was additionally installed at the intake point at the top of the tower to reduce the filter load and enhance the separation needed for the innovative cooling system.

The high degree of technical plant availability in the Alpha Ventus test field proves that the cooling systems for converters and transformers (Fig. 11.6) are thermally correct and functioning. The required provision of active and idle current is likewise maintained. Nevertheless, there is still room for operational improvement such as better installation devices for fast connection of the power cables, use of a smaller transformer cooler or the construction of even more compact medium-voltage switchgear. This has been achieved in the following offshore wind turbines of type AD 5-116 and in the prototype of AD 5-135. But it was the test operation in Alpha Ventus that opened our eyes to this.

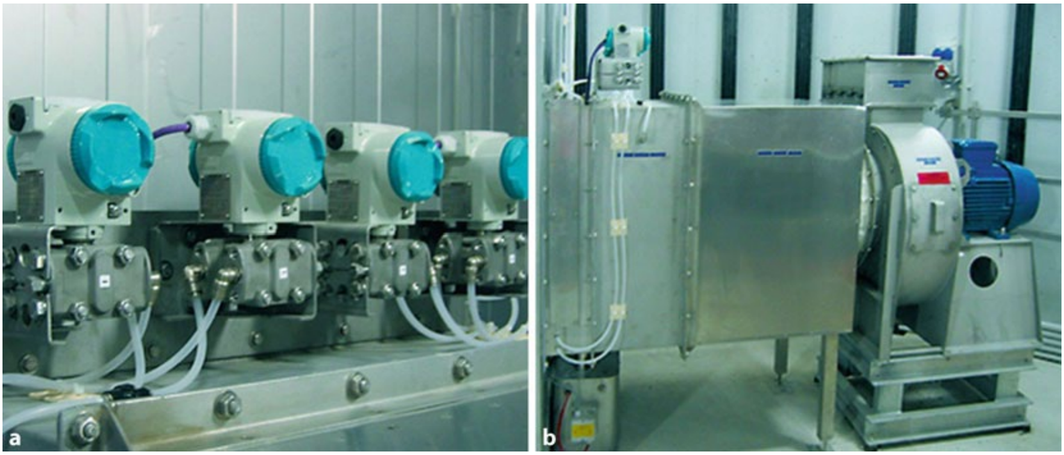

Fig. 11.6 Internal cooling (a,b) Adwen AD 5-116. © Adwen

11.6 Maintaining Maintenance

Maintenance concepts and condition monitoring systems for constant surveillance play a vital role in the operation of wind turbines at sea. There was not much experience available in the offshore business when the Alpha Ventus project began. The wind farms that had already been built at this time were in the Baltic and there were initial pioneering projects in the Danish and British North Sea but these were close to the coast and in shallower waters and therefore not to be compared with Alpha Ventus.

There was hardly any useful "literature" available on offshore maintenance and monitoring concepts either. What remained was an exchange of information by word of mouth: Adwen held talks with the operators of offshore wind farms. Onshore operation of the prototypes of the AD 5-116 in Bremerhaven over a period of several years provided a framework of data and experience in maintenance and monitoring. These data and statistics contributed to the development of a monitoring system for the offshore wind turbines in Alpha Ventus which in turn was adapted and successfully implemented to simplify inspection of the offshore plants. The potential has not yet been exhausted, particularly in the case of structural measurement data to measure the vibration of the tower and rotor blades. Data analysis to establish the actual strain on the mechanical components is therefore an area of constant development.

Various types of vessels for use in construction and maintenance were also tested. These included accommodation vessels for the technicians who can, if necessary, remain at sea for up to three weeks.

11.7 Keeping in Touch …

The times when only the manufacturer was in possession of a special electronic interface to "their" wind turbines are long past. In wind farms the turbines of different manufacturers must be combinable and compatible across the system in terms of SCADA (Supervisory Control and Data Acquisition) – this was one of the specifications in the Alpha Ventus research project. And it was fulfilled. The server that was developed is completely compatible with the SCADA systems of other manufacturers. The new standard interface enables the AD 5-116 to be used in mixed wind parks with several different types of wind turbine. This also means that the additional expenditure in the development of SCADA systems is kept to a minimum. The new interface is also used in the neighbouring wind farm Trianel Windpark Borkum (40x AD 5-116), which was built in 2014.

11.8 Keep Turning in High Wind …

Wind turbines usually switch off in high wind. They change into the so-called idling mode to keep the enormous strain on the foundation to a permissible limit. In the case of AD 5-116 this occurs at wind force 10 and can result in a loss of power yield, particularly in high-wind offshore locations.

The engineers have devised a solution for this that enables the continued operation of the offshore wind turbine at reduced power during high wind. The newly developed control strategy pitches the blades to a position away from the wind to reduce the pressure on the rotor and therefore the strain on the foundation. A new type of sensor system additionally recognises peak loads and uneven stress on the rotor before the situation becomes critical. The plant reacts automatically with individual pitch control (IPC) for each blade and can therefore avoid short-term extreme loads. This regulation strategy results in an increase of the annual power yield but not of the load level.

Peripheral Anecdote (I): One plant with many fathers!

Ingo de Buhr (then Prokon-Nord) was the first and only planner of a wind farm project to take on the challenge and become a manufacturer of wind turbines. He took over the Multibrid development corporation of the Bavarian wind turbine manufacturer Pfleiderer and thereby "inherited" the plans for a multi-megawatt machine together with a patent licensing agreement with the plant developer Aerodyn. After the prototype had been built on land, the exclusively offshore machine with Multibrid M5000 technology was first implemented in Alpha Ventus. The French energy concern AREVA joined Multibrid at the end of 2007 and took over 100 % of the shares in 2010. The joint venture Adwen Offshore was established in 2015 between the Spanish manufacturer Gamesa and AREVA who have brought their M5000 wind turbine types AD 5-116/AD 5-135 and their offshore projects entirely into the new enterprise.

Björn Johnsen

11

11.9 Helicopter Air-Drop Platform: Abseil!

To avoid any misunderstanding: air-drop here means abseiling. But this has nothing in common with a safe descent on firm ground! Helicopter air-drop platforms are needed for emergencies or perhaps essential quick maintenance work when a vessel cannot approach the wind turbine because of high wind and waves. Here again there were at first no DIN standards at all in respect of offshore wind energy. At the beginning of the project the only advice came from international regulations which was more or less "Heli-decks on offshore (oil) platforms, please be kind enough to comply". After the construction of the German offshore wind energy test field, the minimum requirements for helicopter air-drop platforms on offshore wind turbines were legally established in Germany. The "Principles of the Federal Republic of Germany for Service Areas on Wind Turbines" have applied since 2012 (Federal Gazette of 27.01.12). The helicopter platform (Fig. 11.7) built for the AD 5-116 was accepted and approved by the Federal Maritime and Hydrographic Agency (BSH) and the Federal Ministry of Transport, Building and Town Development; certification was by Germanischer Lloyd (DNV GL). A patent is pending, and the economic potential is high: these helicopter decks were subsequently also installed on the 40 wind turbines in the neighbouring wind farm Trianel Windpark Borkum in 2014 and the 80 wind turbines in the offshore wind farm Global Tech I.

11.10 Drivetrain in Long-Term Test

Trust is great, control is better. For everyone concerned. In order to find out exactly what loads the main components in the drivetrain are subjected to, the drivetrain of an AD 5-116 was completely taken apart and examined. After four years of service and production of 38 gigawatt hours of power. In particular, the suppliers of the components were invited to take part in the assessment because they also profit from the findings obtained. Interim result after four years: the encapsulation of the wind turbine works and lives up to expectations, all screw connections

Fig. 11.7 A technician is lowered onto the winch platform for a service assignment. © Adwen/Jan Oelker

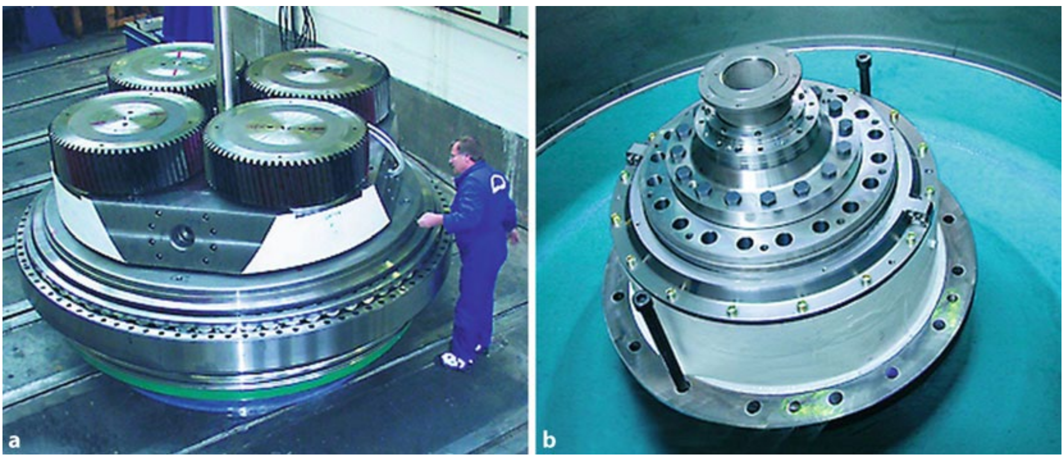

Fig. 11.8 Planetary gear (**a**), detailed view (**b**). © Adwen/Jan Oelker

were free from corrosion and easily loosened. According to the assessment of independent experts, the rotor blades are in a normal condition in consideration of their operational service.

The blade bearings with raceways, cage, rolling elements, gear teeth and sealing were flawless according to the manufacturer present during the examination. They could well reach their expected service life of 20 years. The main bearing with raceways, cage and rolling elements was also in a good condition, said the component manufacturer. As expected, close attention was paid to the gearbox, which was removed and then examined by independent experts. They pronounced that there was no reason to change the design of the gearbox (Fig. 11.8). The large slide bearing C (near the oil pocket) is free from significant deformation and can continue to be used. There was no indication of overheating or false oil circulation. The gearbox is therefore in a good condition. Nor were there any complaints when the generator was inspected.

Overall conclusion of the experts about the "used" drivetrain: the technical concept of the offshore wind turbine AD 5-116 was confirmed together with the materials used and the design of the components. All findings are important because

Fig. 11.9 A view inside the assembly shed. © Adwen/ Heike Winkler

they may on occasion lead to improvements and, in particular, lead to more exact data concerning the service life of the components. The significant results of a technical examination are important for the financial feasibility of future offshore wind farms. By the way, the drivetrain was reassembled and returned to service (Fig. 11.9).

11.11 Sources

- Innovative Weiterentwicklung, Konstruktion und Test der Offshore Windenergieanlage AREVA Wind M5000 unter erschwerten Offshore Bedingungen im Offshore Testfeld Borkum West. Abschlussbericht, 2014, Förderkennzeichen 0327670
- ► www.adwenoffshore.com, accessed on 22.11.2015