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BLYTH HARBOUR WIND FARM - OPERATIONAL ASPECTS

AMEC Energy Ltd

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dti

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EXECUTIVE SUMMARY

This is the last of seven reports to be published on specific areas covered by the monitoring and evaluation of the Blyth offshore wind farm project. The purpose of the reports is to explain the evaluation and review of the practical aspects of installation, access, operation and maintenance of the first UK offshore wind farm.

The other W/35/00563 reports are as follows:

- Installation and Commissioning
  REP/1
- Navigational Requirements for UK Offshore Wind Farms
  REP/2
- Projected Capital Costs of UK Offshore wind farms based on the experience at Blyth
  REP/3
- Health and Safety Guidelines
  REP/4
- Projected Operation and Maintenance costs of UK Offshore wind farms based on the experience at Blyth
  REP/5
- Review of Operational Aspects REP/6

1) THE AIM AND OBJECTIVES OF THE WORK

The principle aim of this report is to review the actual wind turbine performance against expectations. The wind turbine performance was monitored against the predicted performance, including power curve performance, wind regime and availability.

2) BACKGROUND TO THE PROJECT

The wind farm off the coast of Blyth, Northumberland, is the first offshore wind farm to be built in the United Kingdom. Two 2MW wind turbines have been installed at a distance of approximately 1km from the coast, in a water depth, at low tide, of about 6m with a tidal range of approximately 5m. The completed project is the first in Europe to be exposed to the full force of the North Sea weather as well as a significant tidal range. The site is also subject to breaking waves.

The site location is on a submerged rocky outcrop. Each wind turbine has been erected onto a steel pile (monopile) that was drilled and grouted into the rock. The 3.8m diameter holes for the pile were drilled from a jack-up barge (the Wijslift), and the pile lifted off the supply barge by the crane on the jack-up barge and allowed to sink into the drilled socket. The monopile was then grouted into position and allowed to cure. When it had been confirmed that the monopile was secure in the hole, the sequence of erection was tower, nacelle and finally the rotor with the three blades attached.

The site has the benefit of all the consents required for the installation of the turbines. An Environmental Assessment was produced and detailed site investigation studies were carried out and evaluated in order to complete the detailed design of the structure.

The Blyth Offshore Wind Farm has been developed by Blyth Offshore Wind Limited, a joint venture company between Powergen Renewables, Shell, Nuon and AMEC Wind. The diversity of experience and skills within these organisations has been brought together to pioneer the first project in what promises to be a new and exciting industry for the UK.

3) TECHNICAL PERFORMANCE

The turbines have suffered from poor availability for the first three years. This has been due to several causes, but mainly due to inadequate testing of the prototype to this design. A major design review was carried out across this series of machines and a retrofit programme carried out. The retrofit programme appears to have resolved the availability issue.

The performance of the turbines when operating has matched the specification.

The wind farm has also suffered a cable fault due to installation deficiencies and a lightning strike which destroyed a blade.

4) CONCLUSIONS

The project has demonstrated the difficulties of operating a wind farm at sea. It has highlighted the importance of thorough testing of machines before they are installed. The importance of design of every single component has also been demonstrated clearly, as there were no major design issues just lots of small ones.

The importance of robust installation designs was demonstrated by the cable fault. The importance of robust contingency plans was demonstrated by the delay in replacing the damaged blade and generators. Better planning could have saved a lot of time.

CONTENTS

1 INTRODUCTION

1.1 Background

The wind farm off the coast of Blyth, Northumberland, is the first offshore wind farm built in the United Kingdom. Two 2 MW wind turbines have been installed at a distance of approximately 1km from the coast, in a water depth, at low tide, of about 6m with a tidal range of approximately 5m. The completed project is the first in Europe to be exposed to the full force of the North Sea weather as well as a significant tidal range. The site is subject to breaking waves.

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The Blyth Offshore Wind Farm has been developed by Blyth Offshore Wind Limited (BOWL), a joint venture company between Powergen Renewables, Shell, Nuon and AMEC Wind. The diversity of experience and skills within these organisations has been brought together to pioneer the first project in what promises to be a new and exciting industry for the UK.

A flow diagram showing the different responsibilities of the companies is included in Appendix A.

The BOWL board appoint a General Manager as their representative to oversee the operation of the wind farm. The daily operation of the wind farm is the responsibility of the Operations Manager (AMEC Wind Energy) and the maintenance of the wind farm is contracted to Vestas under the Warranty and Maintenance Agreement.

1.2 Aims & Objectives of this Report

The principle aim of this report is to review the technical performance of the offshore wind farm. The report covers the availability and power curves of the turbines and the performance of ancillary equipment.

TURBINES

1.3 Background

The Blyth Offshore wind farm consists of 2 x V66 2MW Vestas wind turbines. The communication to the wind farm is through a standard Telecom system operated with the VRP (Vestas Remote Panel) software.

Both turbines are of the standard type nacelle and blades, which means no changes to the normal six monthly maintenance and operation of the turbines in general. The turbines have a tower of hub height 67 metres and a rotor diameter of 66 metres.

The blades are made of glass fibre reinforced epoxy. All functions of the wind turbine are monitored and controlled by microprocessor-based control units. This control system is placed in the nacelle.

The glass fibre reinforced nacelle cover protects all the components inside the nacelle against rain, snow, dust, sun etc.

The wind turbine is designed for ambient temperatures ranging from -20°C to +40°C. The corrosion protection on the rotor and nacelle is according to ISO 12944-2 for corrosion class C5-M (outside) and C4 (inside). The steel tubular tower also has corrosion protection according to ISO 12944-2 for class C5-M (outside) and C4 (inside).

1.4 Additional Measures for Operation in Marine Environment

The foundation monopile design was modelled and tested for wave loading utilising design and fatigue load cases.

The turbine door was designed and manufactured to be water tight and situated on the ‘shore-side’ of the turbine so that even if waves break at the same height as the door, they don’t break against the door.

The main flanges of the wind turbine structure were bolted so tightly together so that not even water would seep through and all bolts were fitted with rubber washers to prevent against saline ingress and corrosion.

There were also several holes in the wind turbine tower that were used for cabling for the navigational aids and the bird camera. The holes were packed using waterproof cable glands so as to not let any water in.

The turbines were specially developed for offshore including special corrosion protection on external surfaces and heating / dehumidification of the nacelle. If the high voltage network is de-energised for any operation or maintenance work it must be switched back on as soon as it is safe to do so to ensure that the heaters in the turbine are only off for the minimum amount of time. Even if there is no wind and the turbines cannot generate the power must be on to keep the heaters going in the nacelle.

1.5 Modifications Performed Since Commissioning

There have been many modifications to the turbines since they were installed. As a result of problems with this series of turbines the manufacturer of the turbines, Vestas undertook a systematic and thorough review of the design and the problems experienced. This took time most of 2002. It resulted in a retrofit programme to implement a significant number of changes. This programme was completed on the Blyth turbines in 2003. In the period before the retrofit the turbines were kept running with many interventions of a temporary nature.

The major overhaul programme included the following items

- modifications to the hydraulic system, including the pump and control valves
- modifications to the generator rotors, generator mounting and generator cooling system
- additional contactor features and replacement of some relays
- modifications to the yaw system
- installation of arc detections system, shields and new mounting brackets for the transformer
- upgrade to software
- changes to the lubrication system

Most areas of the turbine were modified, reflecting the lack of testing of the prototype in a harsh wind environment. No fundamental designs flaws required rectification. As can be seen from the availability section, small problems can dramatically affect machine performance especially given the access issue offshore.

This proves the value of full testing and failure mode and effects analysis for future offshore machines.

The turbine availability only began to improve once all the modifications had been carried out in late 2003.

1.6 Operation

The turbines began operation in December 2000.

2.4.1 Cable Fault

In early 2001, there was a cable fault on the link between the two turbines. This was the result of poor installation. The attachment of the cable to the seabed was to be carried out by divers. The installation of the cable was carried out in October and the visibility became poor. The contractor thought enough had been done to secure the cable for the winter and planned to finish the work in the spring. Unfortunately this was not the case.

The cable protection where the cable left the J-tube came loose and slipped down the cable. The current then caused the cable to wear on the end of the J-tube and the cable was cut through. There was sufficient spare cable in the link to allow the damaged section to be pulled into the tower and cut off. However the spare length was at the far end and had to be worked along to the appropriate end. There were three attempts to do this, mainly frustrated by combinations of weather and tides. In the end the entire length of cable was suspended on floatation bags and pulled along with a small tug. Again this was a diver operation and required good visibility. The cable was out of service for approximately three months.

The cable was then secured at intervals to the sea-bed and the supports at the entrance to the J-tubes were supported by shaped cement filled bags. A video of the cable route and securing arrangements was made for reference.

Spare cable for a repair was available but was not needed in this case.

The lessons learned from this problem were;

- try to use installation methods with no or very little diver intervention
- the detail of the cable entry is very important and requires close cooperation between the steelwork designer and the cable laying contractor
- detailed repair strategies need to be worked out in advance.

2.4.2 Lightning Strike

In early 2003 one turbine was struck by lightning and a blade folded in two, but remained attached.

After detailed investigation the following chain of events is believed to have occurred. At the very end of 2002, there was lightning in the area and the blade was struck. The lightning did not hit the disk near the tip but in the middle. Since it did not immediately flow down the conductor, there was a steam explosion inside the blade (water flashing to steam very fast), which opened the trailing edge and creased the shell along the central spar. The turbine continued to run for a further two weeks. During the next two weeks the blade spar was damaged by fatigue where the shell was attached due to it flapping about. In the next high wind the pressure of the wind on the now weakened spar caused it to fold in half. At this point the turbine stopped.

The blade was replaced a couple of months later using the new A2Sea vessel. The manufacturer preferred to wait until this vessel was available rather than attempt to remove the blade with a winch (as had been indicated as possible in theory during contract negotiations). The blade replacement was carried out very smoothly and quickly when the A2Sea was alongside.

It should be stressed that the blade did not disintegrate.

As a result of this incident lightning strike detectors were fitted which will stop the turbine if it is hit and an inspection is required before the turbine started again.

The procedure for blade exchange needs to include a method not only for removing a whole, structurally sound blade but also a damaged blade or even a blade stub.

2.4.3 Generator Failures

There have been two generator failures.

The first was caused by carbon dust from the brush unit entering the stator, building up on the winding tails and causing a short circuit. The generator was replaced with a one that had modified end shields to remove this problem.

The second failure was due to overheating in the stator windings, causing deformation of the rotor and contact with the rotor. This was caused by poor varnish impregnation of the stator windings.

The generator can easily be removed from the turbine using the internal crane and lowered to a boat. There were however problems landing the generator on a boat. The type of boat is important it needs to large enough to be stable for swell and currents from the front and the side. Several vessels were used with varying success. One other generator was replaced as a precaution.

The lesson learned from this was that the method of generator extraction had been worked out but not the vessel to be used to take the component away. Boats need to be identified in advance, taking into account the likely conditions of wave and current at the site.

1.7 Availability

1.7.1 Anticipated Availability

The contracted availability was 95%. This included the caveat that time waiting for weather to carry out repairs was not included in the unavailable period.

The definition of availability is very important and in this case was a mixture of several definitions with modifications for the offshore environment. It was finalised during contract negotiations and not fully analysed for practical application. Several anomalies only became apparent when the calculations were performed as a result of serious generation time losses. The importance of good weather records including sea state, who records them and when, needs to be emphasised and budgeted for. Precisely what weather conditions are deemed unacceptable – it is easy to write these down, but in reality the access vessel and particular captain can have a big effect.

It should be stated that there were no arguments about these aspects in this project but for the goodwill shown by all parties, there could have been great difficulty.

1.7.2 Availability in First Two Years of Operation

To illustrate the availability over the first three full years of operation, the following graphs have been prepared for each turbine. If there was a problem on a particular day, then the box has been shaded.

Table of Availability for Turbines

Turbine 1870
Year 2001

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th	19th	20th	21st	22nd	23rd	24th	25th	26th	27th	28th	29th	30th	31st
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Turbine 1870
Year 2002

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Turbine 1870
Year 2003

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From the tables the following can be clearly seen

- The cable failure disabling Turbine 1871 in the spring of 2001 and the associated safety outages on the other turbines during repairs
- The blade failure in Turbine 1870 in early 2002
- The generator failure in Turbine 1871 also in the first half of 2002
- The generator failure in Turbine 1870 in early 2003

The continuing little problems and retrofit programme resulted in almost daily visits at other times.

1.7.3 <u>Subsequent Availability</u>

The availability has been poor for the first three years for the reasons given. However form late 2003 the situation has improved, with availability in excess of 95% being achieved. This is due to the success of the retrofit programme.

Power Curve

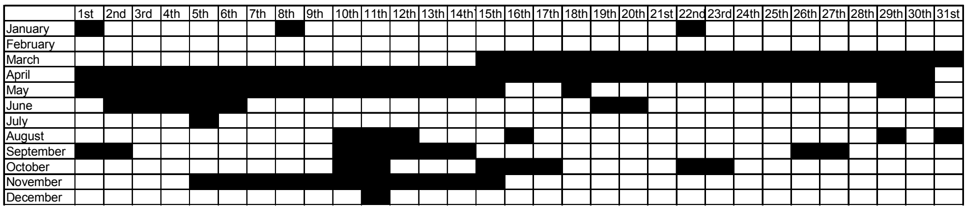
1.7.4 Warranted Power Curve

In accordance with common practice the power curve itself was not warranted. What was warranted was the area under the power curve weighted by a wind speed distribution relevant to this site.

1.7.5 Measurement of Power Curve

The measurement of the power curve was difficult in this location. The installation of an anemometer mast close to this small wind farm at sea could not be justified. Instead an anemometer mast was installed on shore 1.2 km away. The mast was to far away for meaningful measurements, so the anemometers on the nacelles were used. These are obviously affected by the rotor. To estimate this systematic error, measurements form an onshore machine, with an adjacent met mast, were made. The measurements were made at Tjaerborg. These were used to correct the nacelle readings.

Turbine 1871
Year 2001



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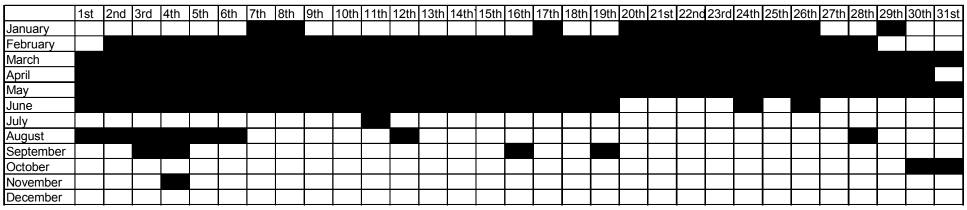
Turbine 1871
Year 2002



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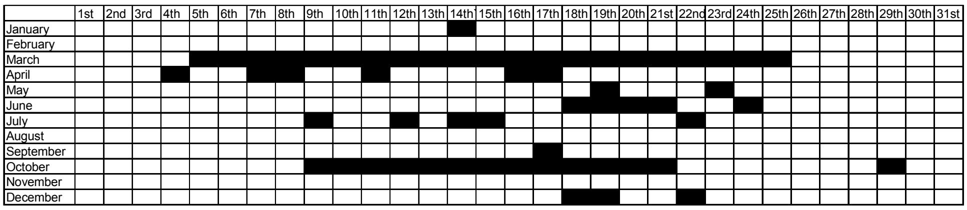
Turbine 1871
Year 2003



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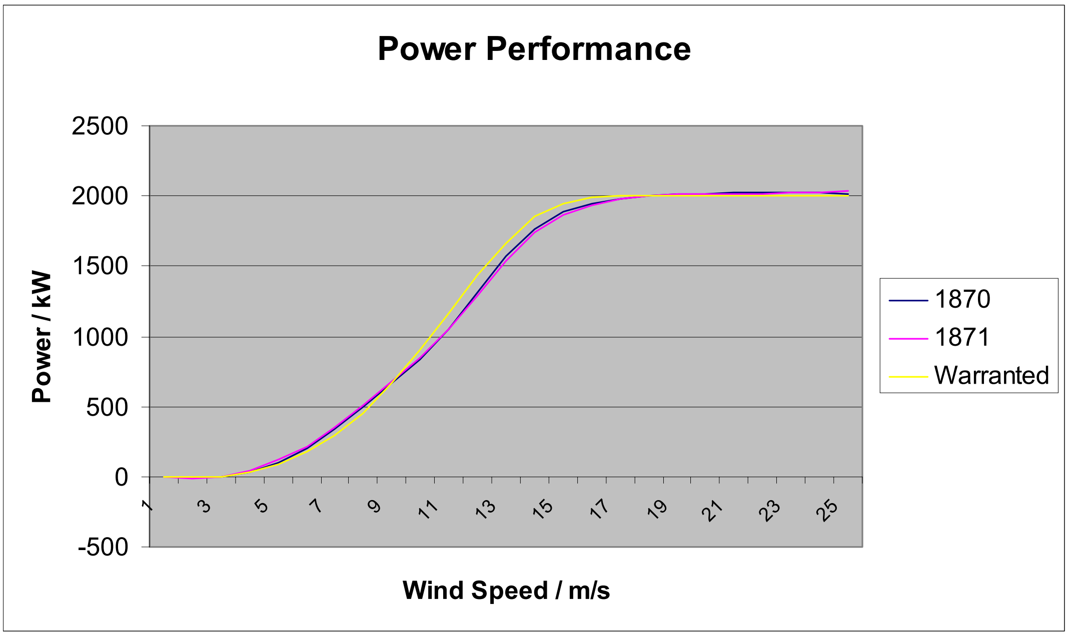
Measured Power Curve

The results are shown in the chart below.

The calculations based on these results gave values of 98% of the warranted value for the weighted areas. The turbines were thus performing within specification when they were generating.



2 FOUNDATIONS

2.1 Structural Steelwork

The steelwork has been visually inspected outside and as far as the water level inside, no corrosion has been observed.

The fenders and platform have not sustained damaged due to the access vessel. However the deck of the aluminium boat used for access has been damaged by the fenders on occasion.

2.2 Access Ladders and Platform

The grating brackets on the platforms have been strengthened as the waves in high seas lifted one or two gratings. This appears to have solved this problem.

2.3 $S0_2$ Production Inside Pile

$S0_2$ (Sulphur Dioxide) was noticed in one tower on entry after about a year. Gas detectors were issued to personnel to warn of dangerous levels (none were ever recorded) and the towers ventilated on first opening the door.

Water samples were taken at various depths inside the sealed pile. These revealed microbes which were producing the gas. These microbes not only produce SO_2 but can also accelerate corrosion. An environmentally acceptable and approved chemical additive was added to this sealed water volume. It was added at several levels and the water vigorously agitated using compressed air to ensure good mixing to the appropriate concentration was achieved. This cured the problem.

2.4 Marine Growth

There has been regular build up of marine growth on the pile and access ladders. This makes the ladders slippery and dangerous. A program of regular cleaning in spring and autumn was instituted. Ordinary pressure washers were tried but found to be too slow. A more powerful washer has been used which can handle sea water. This clears the ladders in about ten minutes.

3 ANCILLARY EQUIPMENT

3.1 Sub Sea Cables

The fault on the cable was described above. This was due to installation problems. During the video survey it was noticed that the polypropylene outer layer was worn off as a result of current action in a few places during the first winter. The wire armour was not damaged and the cable was secured properly after that winter.

3.2 HV Switchgear

The switchgear has performed correctly including during the cable fault.

The only issue has been that condensation has been observed in the cable termination boxes. The dehumidifier has cured this.

3.3 Grid Connection

There have been no issues with the grid connection.

3.4 Navigation Aids

The navigation aids have performed correctly.

The radar reflectors appear to produce a smaller signal than the towers, although they have not been removed to prove this.

3.5 PPE

The buoyancy suits and lifejackets have stood up to the rigours of access without having to be replaced in the three years. They are regularly maintained. However they have not been tested as no one has fallen in.

4 HEALTH AND SAFETY

There have been no accidents during operation. There has been one near miss.

The near miss occurred when a dive support boat engine was started and the propeller turned while a diving operation was underway. The dive master called for the engine to be stopped immediately. The divers were recovered and an investigation carried out. Procedures were tightened and work restarted. The boat in use was under sub contract and the liaison with sub-contractors improved.

The access permit system has worked well. It has been reviewed twice in the three years. After one year the access weather window was opened out to allow access in waves on a peak to trough height of 2m for trained personnel. The wind speed limit was also raised to 20 m/s for winds from the West, as these do not cause waves in this location. Other minor modifications have been made to improve the ease of use of the system as a result of feedback from those involved.

5 CONCLUSION

The project has demonstrated the difficulties of operating a wind farm at sea. It has highlighted the importance of thorough testing of machines before they are installed. The importance of design of every single component has also been demonstrated clearly, as there were no major design issues just lots of small ones.

The importance of robust installation designs was demonstrated by the cable fault. The importance of robust contingency plans was demonstrated by the delay in replacing the damaged blade and generators. Better planning could have saved a lot of time.