Wind Turbine Technology Offshore

J R C Armstrong
J A Consult[*]

SYNOPSIS

This paper looks at modern trends in onshore turbines, and the extent to which these turbines will be used offshore. The results of an analysis of onshore and offshore installations are presented, showing how the cost drivers differ offshore, and what this could mean for the future direction of technology developed specifically for offshore. For instance, two-bladed concepts offer cost advantages offshore without the acceptability problems encountered onshore, and these advantages are particularly marked for direct drive generator concepts.

Computer animations of potential offshore schemes can be used to illustrate how the technology could develop. The schemes described here include those which can be realised with today's technology, as well as a more speculative look at concepts for tomorrow.

INTRODUCTION

The placing of wind turbines offshore is likely to lead to developments of the technology as far-reaching as those which turned the crude onshore machines of the early 1980's into the elegant giants of today. Cost drivers will differ offshore, with large projects of 50 MW+ and a premium on high reliability, efficient access and as much self-maintainability as possible.

Designs will have to be very well proven before being mass-installed offshore. Turbine technology will therefore lag some way behind where it would optimally be, as the proving is done onshore. In the short term, technical innovation will tend to focus on non-turbine aspects: support structure, foundations, installation and maintenance equipment and methods, and machine diagnosis and health check systems.

However, the pressure to reduce turbine cost will continue unabated. Improvements will come about naturally through more efficient procurement and production methods, but there are also clues as to the direction that designs will take. Jamieson (Ref 1) points out that the most effective way of reducing weight, and therefore cost, is to increase tip-speed and reduce torque. Onshore, noise sensitivities impose limits on what can be achieved, but offshore there is no such limit. We can therefore expect to see tip-speeds rise here.

Direct drive generators – removing the need for transmission gearboxes – offer the prospect of simplicity and high reliability. Bohmeke et al (Ref 2) compared the costs of turbines with conventional transmissions and with direct drive generators having totally enclosed windings which would be suitable for offshore. Although the direct drive generator turbine had 18% higher initial cost, its lower O&M requirement narrowed this difference so that

---

[*] ***J A Consult***: 76, Dukes Avenue, London W4 2AF
0181-994-2645: johnarmstrong@jac.ndirect.co.uk

the all-up lifetime cost was similar. Bohmeke favours wound generators in place of permanent magnet types because of lower cost, but the latter have the advantages of lower size and weight, with higher part-load efficiency. Also permanent magnet costs are falling. At least one manufacturer is marketing a 600 kW turbine with a permanent magnet direct drive generator.

The main objective of this paper is to examine some of these claims and speculate about the direction of the technology offshore in the medium and long term.

A secondary objective of the paper is to emphasize the role of computer animations in visualising and presenting potential technical solutions. These will be shown in the conference hall presentation of the paper. Still shots are included below to give an idea of the potential of this process. The four minutes of AVI file animations shown were created primarily using Truespace 3.2 software on a fast standard desk-top PC. 6000 separate frames were rendered from wireline models of turbines and scenery, taking 200 hours of processing time and occupying 150 Mb of disc space.

ONSHORE STATE OF THE ART

Onshore turbines creep on upwards in size. Although 600 kW turbines are becoming standard in Britain, 1 to 1.5 MW is common in Germany, 2MW machines are under development and there are rumours of much larger designs on the drawing board.

There is also a trend away from tip brakes and passive stall rotors, which dominated the industry in the 1980's. The need to control loading and power output favours pitchable blades. Some manufacturers feather blades for braking, speed control and power regulation; others adopt a variety of strategies around pitching the blades towards stall to achieve the same result.

Figure 1 depicts a number of typical 1.5 MW 63m, pitch-regulated three-bladed turbines situated around a lake.

TWO BLADES FOR OFFSHORE

It is probable that the first turbines installed in large windfarms offshore Britain will be MW turbines well-proven in Germany and Denmark. Stretches of these three-bladed turbines to 2 MW or so will be not far behind.

As mentioned in the Introduction, the most effective way to stretch performance even further is to increase tip speed and reduce torque. However, there is a limit to how fast a three-bladed rotor can be made to run: each blade cannot be made too slender because the loading becomes too high and the handling too difficult. The present commercial maximum of 75 m/s is unlikely to be pushed much higher.

A two-bladed rotor, however, can be made to run that much faster before blade slenderness becomes a problem. Tip speeds of 90 m/s and over are feasible[*]: unacceptable onshore because of the noise, but less of an issue offshore. Nor is the visual appearance of two blades – which is criticised in some quarters onshore – likely to be a problem offshore.

The increase in allowable tip speed reduces torque for a given power. This means that a three-bladed rotor can be replaced with a two-bladed one and the transmission and torque-sensitive structures made lighter and cheaper. Alternatively, a larger two-bladed rotor can be fitted to a given nacelle and transmission frame-size to capture more energy.

The trade-off in the latter case is the higher cost of the larger blades and teeter mechanism, offset by the fact that there is one blade less; against the increased energy capture of the larger diameter, offset by the slightly lower aerodynamic efficiency of two blades compared to three.

What about other structural implications of two blades? The larger rotor will be heavier, and although the teeter mechanism will reduce other loads on the nacelle and main bearings, teeter impacts in turbulent winds will still have to be accommodated. Offshore, turbulence is usually low, so these impacts may not be serious. However, this low turbulence is also associated with low wind shear, which means that high towers are unlikely to be justified by

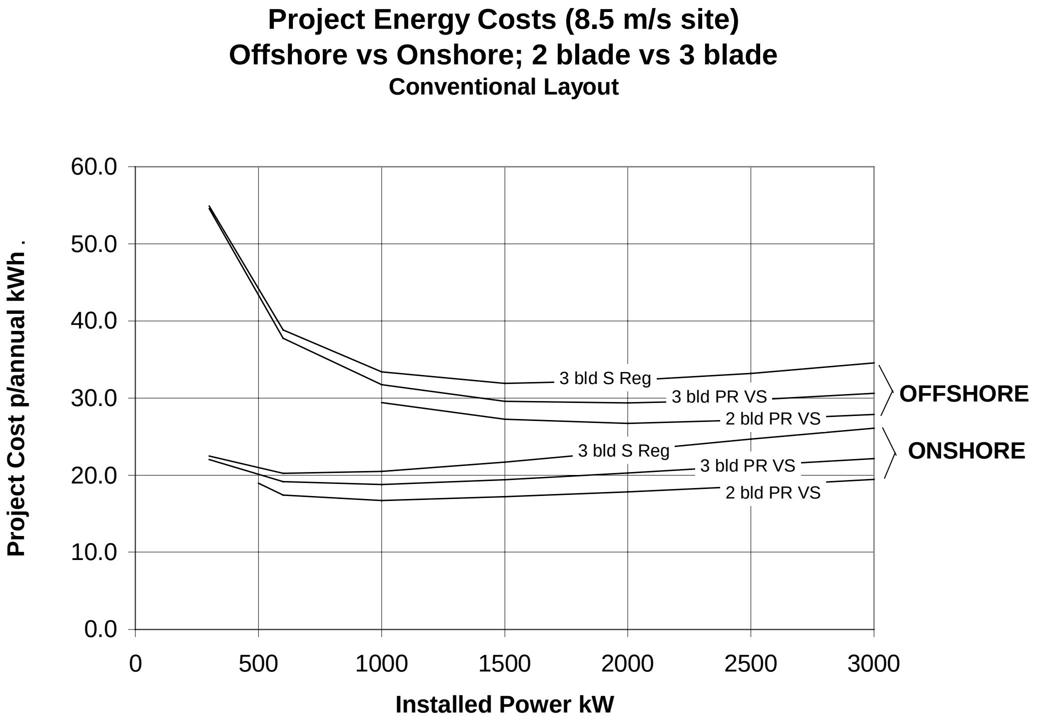
---

[*] The Orkney 3 MW machine ran at up to 108 m/s

increased energy capture, and the lowest towers compatible with spray and wave clearance will be used. The larger rotor of a two-blader will therefore need a higher tower, offsetting some of the cost benefit.

To look at the effect of all these factors, a spreadsheet analysis of two and three-bladed turbine projects, onshore and offshore UK, was developed. This model uses simple algorithms to predict component weight and cost, based largely on the author's experience of wind turbine development over the years. For instance, blade weight is assumed to vary with the 2.5th power of size, gearbox weight and cost varies with input torque, foundation size varies with overturning moment, and so on. Allowances were made for large project add-ons, installation and logistics in deriving a capital cost of energy in terms of pence per annual kWh. No allowance was made for O&M requirements, nor for some of the step-change functions of equipment availability and frame-size limits which are going to be very significant offshore, but which are impossible to predict in a general case.

The results of the analysis, for an 8.5 m/s site, are shown below.



The model compares three concepts:

- 3 blades, stall regulation
- 3 blades, pitch reg, variable slip
- 2 blades, pitch reg, variable slip.

Onshore, there is little difference between stall and pitch regulation for sub-MW three-bladed turbines, as is found in commercial practice. The advantage of pitch regulation becomes more apparent at larger size because of load control and weight reduction. This would be even more marked for large two-bladed turbines.

Offshore, the story is similar, except that the optimum size increases to around the 2 MW level (although the curves are so flat-bottomed that there is no precision here, and other factors such as equipment availability are likely to be more significant). Again, the benefit of the two-bladed rotor is evident.

In the analysis, rotor size is independently optimised for each value of power. The optimum 2 MW two-blader for offshore has a rotor diameter of 78m and a tower-top weight of 108t. It is about 10% more cost effective than the optimum three-blader.

Figure 2 shows how such 2 MW turbines would look offshore, close-up.

Figure 3 shows how a 100 MW windfarm would appear in a 10 x 7 diameter spaced group between 2 and 8 miles offshore, viewed from the beach.

DIRECT DRIVE GENERATOR

The direct drive generator has seen considerable commercial success in wound form at 500 kW size, and is beginning to be introduced in Germany at 1.5 MW scale. The reliability advantage of having no gearbox has been offset by concerns about the susceptibility of the open windings to a salt-spray environment. The wound generator is also rather large and heavy.

Current developments in permanent magnet generators, with totally enclosed windings, offer a lighter and more compact unit with the benefit of greater part load efficiency than any fully wound device. The one question concerns its capital cost, and whether this can be reduced far enough to make it competitive.

The cost benefits of higher tip speeds become particularly significant with the direct drive generator. With a conventional gearbox and generator transmission, the gearbox does all the torque and speed conversion, so that the generator has no idea at what speed the blades are rotating: - its cost is solely governed by power output and nominal speed. However, the direct drive generator replaces both gearbox and generator: the whole of its weight and cost is therefore speed dependent and will benefit from a higher tip speed.

Not enough is known about the costs of permanent magnet generators to enable an absolute comparison with conventional drives to be made. However, the model was set up using assumptions compatible with the cost and weight proportions given by Bohmeke, and run to give a comparison between three and two blades. This showed that an offshore project developed with 2 MW two-bladed rotors and permanent magnet direct drive generators would have 11 – 12% lower costs than the same with three-bladed rotors.

The compactness of the permanent magnet direct drive generator is shown in Figure 4.

MULTI-ROTOR TURBINES…?

In the longer term, the way in which the technology develops will depend on how the cost drivers emerge. Presumably there will be a trend towards larger and larger installations, just as there has been onshore. But will blade size be limited by fabrication factors – eg moulding, handling and transport constraints? Will the logistics of foundation moving and equipment installation mean that it is cheaper to set a few very large units than several smaller ones? Will the need to service nacelles or rotors at sea level mean that designs with some degree of self-erection are at an advantage?

If the answers to these questions are ‘yes’, then multi-rotor turbines could be viable. One possible configuration is shown in Figure 5. Three 2 MW rotors on direct drive generator pods are slung below the yardarms of a 150m high tower structure. The arms are shaped to cause minimum disturbance to the rotors, which run downwind of them and are coned for load relief. The two outer arms are supported by cables from the centre upright. The entire head, with all three rotors, is yawed downwind about a 5m slew ring located at the thrust centre of the three rotors. Each rotor/generator can be lowered individually on to a service barge. Man access can be gained to each generator pod and rotor via the tower and arms.

The advantage of this arrangement is that a very large unit size can be gained using standard rotor/generator units proven and quantity-produced at economic size. The innovation comes in the means of support and servicing.

Multi-rotor designs have often been mooted and once even built (by Henk Lagerwey). The problem onshore is that they look messy, and it is simpler and more elegant to achieve the same swept area with a larger rotor. Offshore, different drivers may produce a different answer.

KITE TURBINES…..???

Moving along from the futuristic to the bizarre….. Tethered buoyant structures have often proved their worth when a fixed structure would have been too expensive: semi-submersible drilling rigs, floating production platforms, tethered anemometry balloons. Why go to all the expense of a ground-based tower for the meagre winds a few tens of metres up? If we are after energy from the wind, let's go where the wind is strongest – several hundred metres up[*]!

It is very easy to dismiss such a crazy idea: how would the rotors stay up, how would they get up and down, what about cable twist, power cuts, low-flying aircraft and so on. So are kite rotors at least technically possible?

Figure 6 shows a possible scheme. The flying part, looking rather like a set of chromosomes, consists of a pair of contra-rotating two-bladed rotors mounted upwind and downwind of a differential gearbox. (Single-bladed rotors would be even better, operating at higher speed and lower torque). The output shaft drives an upwind generator which also carries the cable tether. Independent pitch control matches the torque from each rotor so that cable twist is avoided. Because the two-bladed rotors are teetered, there is a vertically induced thrust element tending to keep the flying parts flying (for the same reason that a teetered downwind rotor is self-aligning).

The kite turbine gets into the air by motoring its generator, and reverse pitching the blades to helicopter itself up from its seabed base. In the same way, in a dying wind it would fly itself down as the cable was reeled in. This should even be possible in the event of a power failure – the rotors spinning like a sycamore seed – provided there was an auxiliary power source for pitch control and cable reeling.

Sadly, the hardware is almost certain to be too heavy to be supported at moderate windspeeds. The self-aligning shear force from a teetered MW rotor is quite small – perhaps a ton or two, but the weight of two such rotors and transmission will be many tens of times more.

But what a fascinating prospect!

SUMMARY

1. Offshore turbines will use the largest turbines developed and proven for onshore use.
2. Two-bladed turbines will be more acceptable offshore than onshore, and should give 10% lower cost of energy, because of increased tip speed and reduced torque.
3. Permanent magnet direct drive generators with enclosed windings offer reliability advantages for offshore which would help to offset their higher cost.
4. For these generators, torque reduction is particularly valuable: the cost advantage of turbines with two-blades here could be up to 12% relative to those with three.
5. Multi-rotor configurations could be viable offshore, combining large unit size with standard rotor and transmission assemblies developed onshore.
6. The idea of kite rotors is unlikely to fly.
7. Computer animation is a valuable way to explore technical concepts and present the visual aspects of a project.

REFERENCES

1. P. Jamieson; *"Common Fallacies in Wind Turbine Design"*, Garrad Hassan & Partners, 1997.

2. G. Bohmeke, R Boldt, H Beneke; *"Direct Drive, Geared Drive, Intermediate Solutions – Comparison of Design Features and Operating Economics"*, European Wind Energy Conference, Dublin 1997.

---

[*] With a shear factor of 0.1, there is a third more wind speed at 1km height than at 50m, and double the recoverable energy. Jet streams are encountered at several km height, but so is reduced air density.