Proceedings of the Institution of Civil Engineers
Energy 161
February 2008 Issue EN1
Pages 3–6
doi: 10.1680/ener.2008.161.1.3

Paper 800026
Received 21/07/2008
Accepted 01/09/2008

Keywords:
energy/environment/offshore engineering

Briefing: Offshore wind energy—a challenge for UK civil engineering

A. H. Tricklebank, *Gifford, Southampton, UK*

This article aims to provide a brief review of the current position of UK offshore wind energy development, particularly for those who are interested, but not deeply immersed, in the current scene. It is written from the perspective of a civil and structural engineer who has been engaged for some years in the development of a new approach to offshore foundation construction and is concerned that there should be a more visible involvement of the profession in the future development of large-scale offshore and marine renewable energy systems.

1. TERMINOLOGY

The rated capacity of a turbine, commonly used as the indicator of its power, is now generally denominated in megawatts $(\mathrm{MW}) = 10^6$ W. Wind farm size is increasingly quoted in gigawatts $(\mathrm{GW}) = 10^9$ W.

2. INTRODUCTION

2008 saw the long-awaited announcement of the UK government's programme for meeting the country's future energy needs and commitment to EU targets for 20% reduction in carbon dioxide (CO_2) emissions by 2020. Urgent action—on both the demand and the supply side of the energy economy—is needed if substantial progress is to be made in carbon reduction within the next 12 years. This urgency is reinforced by the problems of energy security and oil price rises.

On the supply side, a massive change to the UK's energy generating mix and infrastructure will be necessary during the next 15 years. The ageing stock of nuclear plant will need to be decommissioned, with eight out of nine of the present stations due to be closed before 2023. Government policy is to replace these with new nuclear plants. It is understood that the total capacity of these new power stations will be about 10 GW. Furthermore, substantial decommissioning of ageing fossil-fuelled generation plant by 2017 is planned, driven strongly by the need to meet current environmental legislation including the large combustion plant directive, which imposes strict limits and timetable on the emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and particulates.[1]

In order to fill the gap and help achieve the target for reduction of CO_2 emissions, it is planned that more than 30% of total electricity generation capacity should be provided by renewable technologies within this time scale. Electrical energy will also need to take an increasing role in displacing (directly or indirectly) fossil fuel for transport and heating, making electricity generation an ever more important part of the total energy supply. Distributed energy generation systems and networks may play an increasingly important role in the future, but large-scale generating plants or farms will have to provide the vast majority of the required capacity for the next-generation life cycle and most likely for some considerable time beyond that.

3. WIND TO DRIVE THE WAY FORWARD

Within the renewable mix, wind energy is already a well-established technology and is regarded as the only one that can reliably provide large-scale generating capacity within an acceptable time scale. Both onshore and offshore wind will have an important part to play. In the UK there are significant constraints to the timely expansion of onshore capacity and the UK's huge offshore wind resource is considered to be where the largest expansion can be directed. It is expected that by 2020 some 60% of national wind energy generation will be situated offshore, compared with less than 10% at present. Even so, the UK has recently overtaken Denmark as having the largest installed offshore capacity worldwide.

Licensing of UK sites for offshore development has been undertaken by the Crown Estates with two rounds to date.[2] Round 1 was focused generally on near-shore/shallow-water sites, while round 2 involved some larger sites (accommodating a 1 GW wind farm in one case) further offshore and in moderate water depths. When all the proposed projects are fully developed (notionally by 2012) they will have an installed capacity of 8 GW.

Round 3 was announced in June 2008 and will define a number of sea areas or zones, each to be licensed to a single development company, with an overall total development capacity of 25 GW (Fig. 1). This will therefore pave the way for a total offshore capacity of 33 GW. Achievement of this target will be governed by

(*a*) fundamental environmental constraints—the 12-month long strategic environmental assessment (SEA) project dealing with these is due to be completed by spring 2009
(*b*) planning consents—the 'round 3' process is now underway

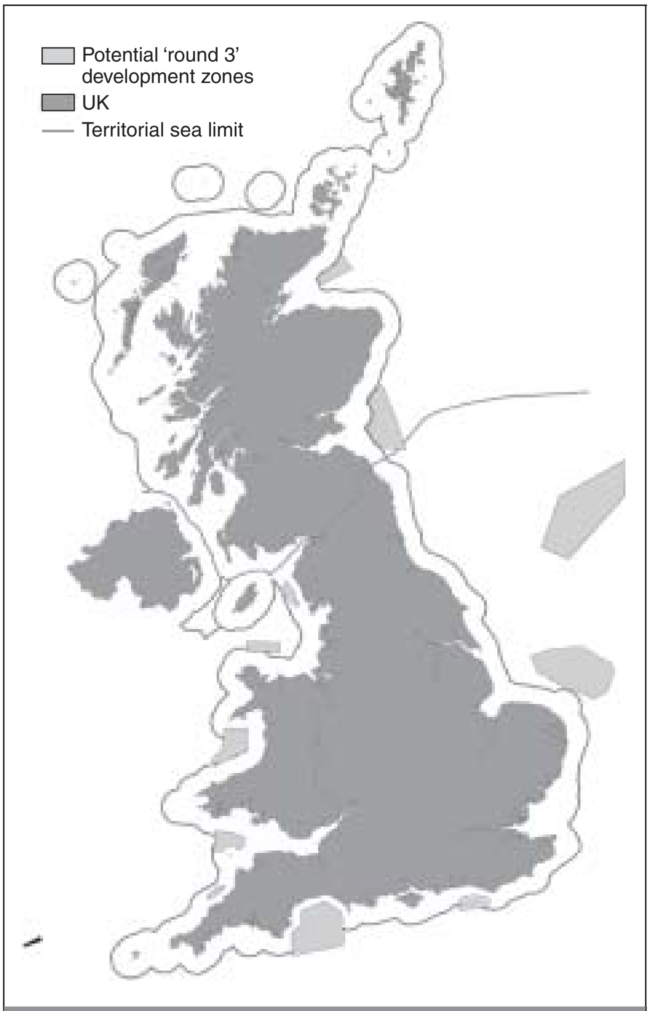

Fig. 1. Indicative zones for 'round 3' offshore wind farm sites. The map represents the Crown Estate's initial view of locations of potential zones for the development of offshore wind farms. It will be subject to revision and the zones do not in any way reflect the output of the government's strategic environmental assessment (expected to be completed by spring 2009). This map is the copyright of the Crown Estate and is reproduced under the terms of their permission

(*c*) economic acceptability
(*d*) strengthening of the UK grid
(*e*) industrial capacity and supply chain.

Each of these considerations represents a major hurdle and overcoming them will require the investment of substantial political will, time and resources. For instance, strengthening of the grid involves building new lines and connection nodes to cater for the geographic disposition of onshore and offshore wind farms, which is very different from that of existing generation capacity. It also involves reinforcement of existing lines and nodes to handle the different patterns of power distribution that will result. Precise figures for the costs involved have not been published, but are believed to be several billion pounds.

Taking a realistic view of these factors, different authorities have predicted that 'round 3' installations will begin in earnest in 2013–14; by 2020, this should amount to somewhere between 6 and 15 GW (1200 to 3000 turbine units).[3] Along with the earlier wind farms, this would provide a total offshore capacity of 14–23 GW. It is expected in this scenario that the mooted overall offshore target of 33 GW (7000+ units) could be achieved in the period up to 2030.

4. WHY OFFSHORE WIND?

The majority of wind farms around the world have been built onshore for the obvious reason that it is an easier place to work, with more benign climatic conditions and easier access to sites. Installation and operating costs for onshore wind farms are, unsurprisingly, significantly lower than for offshore farms and are likely to remain so. Offshore wind turbines and structures are more expensive to install and maintain due to the difficult working environment and the variable and rough sea conditions that prevail for significant periods of time; structures, especially the foundations, additionally have to resist wave loading and therefore have to be stronger than those used onshore.

On the other hand, Britain is a crowded island with a very limited number of large onshore sites suitable and acceptable for wind farm development. For virtually all sites, planning and access are severely constrained. Environmental constraints include landscape considerations limiting tower height (and therefore rotor diameter) and rotor noise, requiring limits on maximum rotor speed. These combine to limit turbine rating, output and efficiency. The dimensions of major components, tower sections, blades and nacelles, are already at or close to the loading gauge limits that can be accommodated on the UK highway network. Some substantial changes in component design and fabrication arrangements would be necessary to allow the economical transport of turbines with ratings much above those in current general use. Taking account of these various factors, it is arguable that the maximum size of turbine likely to be deployed generally for the onshore programme to 2020 is 3 MW or thereabouts.

While offshore conditions provide major engineering challenges, the wind climate is substantially better than that onshore, being more energetic with lower wind shear and less turbulence. Wind shear in this context is variation of wind speed with height from the ground surface. It is caused by surface friction and affects the profile of the wind speed in the near-ground zone and the maximum wind speed in the higher zone. Wind shear increases with ground roughness: it is very low over water and smooth flat surfaces, and of increasing importance for pasture land, undulating ground and built-up areas. It has more marked effects for a limited-height tower and for the lower section of the rotor. It reduces available energy and efficiency of the turbine and induces unbalanced loads and fluctuating stresses on the rotor blades, thereby increasing wear and fatigue in major components. Turbulence is more complex in its distribution but is similarly affected by ground roughness and obstructions, and induces adverse effects similar to those created by wind shear.

Offshore siting also provides other advantages and opportunities. Large site areas are available, starting a few kilometres from the shoreline seawards, occupying only a relatively small length of the coastal perimeter and with little visibility from land. There are fewer environmental constraints related to close proximity to human populations or activities; for instance, turbine noise is less of an issue, thus allowing turbine speeds to be raised. Large structures and turbines can be constructed at coastal/harbour sites and transported offshore without the same restrictions on component size. Offshore wind farm systems are at a relatively earlier stage of development and there are significant opportunities for value improvement.

All in all, offshore conditions allow much larger wind farms, larger individual structures and turbines, more efficient engineering of turbines and generating equipment, and also greater output productivity. Even so, it seems likely that the output cost for offshore wind energy will be higher than onshore wind costs in the foreseeable future. Nevertheless, given the clear limits on onshore development, it will simply not be possible to provide sufficient wind energy capacity in the UK without a substantial offshore programme.

5. FOUNDATIONS AND BASE STRUCTURES

Currently, a typical foundation and support structure for an offshore wind turbine comprises a 4–5 m diameter monopile driven into the seabed to an embedment of say 20–30 m, and projecting above the sea surface. A tubular adjustment or transition piece of slightly larger diameter is fitted over with a grouted connection and this provides a flanged joint for the tower at 15–20 m above the lowest tide level. A tubular tapered steel tower is bolted to this foundation to provide turbine hub heights of 75–90 m above low water.

The offshore wind industry was initially developed by transferring onshore turbine and tower designs offshore using offshore oil and gas industry installation technology and equipment. Steel monopile foundations were well suited technically to this situation and to the shallower water of early developments. They have dominated the offshore foundation scene for the past decade, and, in the case of the UK, to the virtual exclusion of other possible types.

Until recently, developers have almost exclusively favoured engineering, procurement and construction contracts for the procurement of wind farms as these provide substantial risk transfer. This procurement mode and the customary short time scale for tendering, coupled with the uncertain continuity in flow of projects, have had the effect of inhibiting the development of alternative foundation designs and methods of installation.

This next round of development will involve deeper water sites (with water depths probably largely in the range of 20–35 m) and larger turbines (5–7·5 MW). In broad terms, steel monopiles reach their current technical limits under a combination of water depth of 20–25 m and turbine power of 3·6 MW. The required pile embedment, monopile length, diameter, thickness and weight increase to a point beyond the capacity of the largest piling hammers, and towards and beyond the limits for the fabrication, transport and handling of the monopile itself. If the range of the monopile could be extended technically, the ‘super monopile’ would in any case require substantial investment in new equipment and facilities.

New types of foundations must therefore be deployed for a significant proportion of future wind farm developments. Foundations for these more demanding conditions are likely to become a larger proportion of the capital cost, probably somewhere in the range of 30–50% rather than the 20–25% expected for the earlier shallow-water near-shore schemes with turbine ratings of 2–3 MW.

In circumstances requiring new design and construction methods to deal with more adverse conditions, constructors will be less able and willing to accept foundation risk, and developers will necessarily have to engage with the design process earlier and retain a larger share of the risk.

The main contenders for this next generation of designs are listed in Table 1, along with large-scale examples that are being trialled or have been demonstrated during the past two years. Tripods and jackets are piled steel structures, whilst the gravity bases are concrete. The use of different materials is, of course,

Future foundation type	Main material contender	Water depth (typical range of deployment with 5 MW turbine): m	Large-scale demonstrator projects
Tripod	Steel	25–35	• Germany • Onshore trial 2006 • Alpha Ventus 2008/2009 • 5 MW units • 30 m depth • 490 t (not incl. piles)
Jacket (quadropod)	Steel	40–60	• Scotland • Beatrice 2006 • 5 MW units • 45 m depth • 480 t (not incl. piles), 140 t transfer capping
Gravity base	Concrete (prestressed & reinforced)	20–35	• Belgium • Thornton Bank 2007–8 • 5 MW units • 20–27 m depth • 3000 t + ballast

Table 1. Next-generation offshore systems and demonstrator projects

possible but these demonstrators reflect what are likely to remain the mainstream choices for materials for these different types, although perhaps not so certainly the future installation techniques. The foundation/base structures for the demonstrators so far installed have been put in place by large offshore crane barges.

6. OPPORTUNITIES AND CHALLENGES FOR CIVIL ENGINEERS

Much of the engineering focus on the system lies in the disciplines of electrical power, mechanics, control, aerodynamics and advanced composite structures. Offshore engineering has of course also played a big part. Foundations have not been ignored but, as explained earlier, there have been factors inhibiting the broader development of different systems. However, future development trends will put rather more focus on foundations as their share of total wind farm capital cost tends to increase from say 20–25% to 30% or more. Foundation (and base unit) costs for water depths beyond 20 m are likely to be in the order of £0·5–0·6 million per MW. This implies the capital value of foundations for the full 25 GW round 3 programme would be some £12–15 billion.

Foundations for wind farms are often referred to in project documents as a ‘balance of plant’ item, which, even for onshore situations, does not signal their importance. For offshore farms they are central to the engineering and viability of the project. This area provides the biggest opportunities for increasing the direct involvement of civil engineering construction and design skills. There is a general view that it is unlikely existing players will find it possible or appropriate to expand their resources sufficiently to meet the full demands of the UK offshore programme, whether this be in manufacturing or construction. There is thus a strong desire to see new (or retired!) players entering the scene.

In this regard, the UK programme is taking place in a global context of rapidly increasing activity in building wind farms on the one hand and in securing and maintaining oil supplies on the other. Demand for turbines and other major components has become overwhelming, particularly as little additional manufacturing capacity has been added to date, leading to increases in price and delivery times. Offshore oil industry activity has likewise increased, putting a premium on the limited resources of large offshore cranes and installation equipment, and effectively limiting, for the moment, expansion of offshore wind farm building. These pressures seem likely to continue into the future. They should serve to promote interest in local sourcing of major components and the development of fleets of key offshore vessels and equipment dedicated to the wind industry. There are encouraging signs that this is already beginning to happen in the manufacture of large wind turbines, which currently are not produced in the UK.

UK business and industry must actively engage and invest in the offshore wind energy programme over the next few years in order to play a significant role in that programme and in the future development of renewable marine energy around the world. A number of UK-based civil engineering contractors and designers experienced in large marine civil and heavy structures work could provide appropriate expertise and resources—particularly for foundations and base structures. The need for new foundation designs, and for innovation in construction and installation methods, would seem to provide a fresh opportunity for engagement for those who are not currently active in offshore wind energy.

One example of an initiative seeking to accommodate these various factors is a research and development project led by Gifford, in consortium with various specialist designers, constructors and wind farm developers and operators. The project, supported by the UK Department for Business, Enterprise and Regulatory Reform (DBERR) technology programme, was presented at a recent conference.[4–6] It has developed an integrated and economical approach to the design and installation of concrete gravity foundations for wind farms that could provide an entry route for constructors and form part of the essential drive for improved costs and performance for this vitally important future source of energy.

ACKNOWLEDGEMENTS

The views presented in this paper are those of the author, but draw heavily on information published by DBERR and on various presentations at recent BWEA Offshore Wind 2008 and NCE Wind Energy Conferences.

REFERENCES

1. See www.defra.gov.uk/environment/airquality.
2. See www.thecrownestate.co.uk/our_portfolio/marine/energy_telecoms/offshore_wind_energy.htm.
3. Department for Business, Enterprise and Regulatory Reform. *Renewable Energy Strategy Consultation*. Available at http://renewable consultation.berr.gov.uk.
4. Tricklebank A., Halberstadt P. and Magee B. *Concrete Towers for Onshore and Offshore Wind Farms—Conceptual Studies*. Concrete Centre, Camberley, 2007.
5. Tricklebank A. Concrete towers—an emerging competitor. *British Wind Energy Association Offshore Wind Conference*, London, 2006.
6. Brook-Hart W. Gravity foundations for offshore wind farms streamlining construction and installation. *New Civil Engineer Wind Energy Conference*, London, 2008.

What do you think?
To comment on this paper, please email up to 500 words to the editor at journals@ice.org.uk

Proceedings journals rely entirely on contributions sent in by civil engineers and related professionals, academics and students. Papers should be 2000–5000 words long, with adequate illustrations and references. Please visit www.thomastelford.com/journals for author guidelines and further details.