Offshore Wind Energy in Europe

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SYNOPSIS

After several decades of theoretical developments, desk studies, experimental wind turbines and prototype windfarms, the first large-scale commercial developments of offshore windfarms are now being built. To support and accelerate this development, the European Commission is funding a project, 'Concerted Action on Offshore Wind Energy in Europe' (CA-OWEE), which aims to gather and distribute knowledge on all aspects of offshore wind energy, including: offshore technology, electrical integration, economics, environmental impacts and political aspects. The partners are from a wide range of fields and include developers, utilities, consultants, research institutes and universities.
Information will be freely disseminated through a web site, www.offshorewindenergy.org, printed reports, and via the EWEA Special Topic Conference on Offshore Wind Energy in Brussels on December 10th - 12th this year (2001).

INTRODUCTION

Offshore wind farms promise to become an important source of energy in the near future: it is expected that within 10 years, wind parks with a total capacity of thousands of megawatts will be installed in European seas. This will be equivalent to several large traditional coal-fired power stations. Plans are currently advancing for such wind parks in Swedish, Danish, German, Dutch, Belgian, British and Irish waters.

Onshore wind energy has grown enormously over the last decade to the point where it generates more than 10% of all electricity in certain regions (such as Denmark, Schleswig-Holstein in Germany and Gotland in Sweden). However, this expansion has not been without problems and the resistance to windfarm developments experienced in Britain since the mid 1990s, is now present in other countries to a lesser extent. One solution, of avoiding land-use disputes and to reduce the noise and visual pollution, is to move the developments offshore, which also has a number of other advantages:

availability of large continuous areas, suitable for major projects,

higher wind speeds, which generally increase with distance from the shore (Britain is an exception to this as the speed-up factor over hills means that the best wind resources are where the turbines are also most visible),

less turbulence, which allows the turbines to harvest the energy more effectively and reduces the fatigue loads on the turbine,

lower wind-shear (i.e. the boundary layer of slower moving wind close to the surface is thinner), thus allowing the use of shorter towers.

But against this is the single very important disadvantage of capital cost:
there will be additional cost due to the more expensive marine foundations,
more expensive integration in to the electrical network and in some cases an increase in the capacity of weak coastal grids,
more expensive installation procedures and restricted access during construction due to weather conditions,
limited access for O & M during operation which results in an additional penalty of reduced turbine availability and hence reduced output.

However the cost of wind turbines is falling and is expected to continue doing so over the coming decade and once more experience has been gained in building offshore projects, the offshore construction industry is likely to find similar cost-savings. Onshore wind energy is an increasingly cost-competitive resource at a stable price compared to conventional power generation, especially when environmental benefits are accounted for. Hence it would seem likely that offshore wind energy will also become competitive in time. Other developments that are likely to support this trend are the design of turbines optimised for the offshore environment, of greater sizes (maybe up to 10 MW and over 125 m rotor diameter eventually) and with greater reliability built-in. At the moment, the largest production machines have generating capacities of up to 2.5 MW but machines with power outputs of up to 5 MW are planned for production by the middle of this decade. The wind turbine manufacturing industry has been following its own exponential growth curves over the last decade of decreasing costs by 20% and doubling the size of the largest commercially-available turbine every three or so years.
The total wind power resources available offshore are vast and will certainly be able to supply a significant proportion of our electricity needs in an economic manner. Earlier studies by Garrad Hassan and Germanischer Lloyd concluded that a large proportion of Europe's power could be supplied from offshore wind turbines (5) (8).

A BRIEF HISTORY

The first wind turbine to generate electricity was a traditional wooden windmill converted by Poul la Cour in Denmark over 100 years ago. In the early part of the 20th century, there were further experimental machines but serious developments only began with the two oil shocks in the 1970s, when governments around the world reacted by directing R&D money to alternative fuel sources. The early '80s saw major developments in California and the construction of the famous fields of hundreds of small turbines and by the end of that decade there were 15,000 turbines with a total generating capacity of 1,500 MW in that state (1). The stabilising of the oil price in the '80s and resulting reductions in the state subsidies for windpower, meant that purchases from the crucial American market dried up and many wind turbine companies withdrew from the field or went bankrupt. An exception was in Denmark, where government support meant that the knowledge base was not dissolved and the companies there were able to quickly respond when wind energy's fortunes recovered once more in the early '90s, to the point where they and their partners dominate the market today. It should be pointed out that the foundations of renewable energy's fortunes are today based on the solid necessity of alleviating climate change and increased energy autonomy rather than the fickle nature of oil prices.
Currently there is a total installed capacity of approximately 20GW on land and over the last couple of years the annual installation rate has reached 4GW/annum. The average rating of turbines being installed is now around 1MW per unit internationally, Figure 1. With the resulting economies of scale, wind energy now competes on price with the traditional generators, such as coal and nuclear, in areas of rich wind resources.

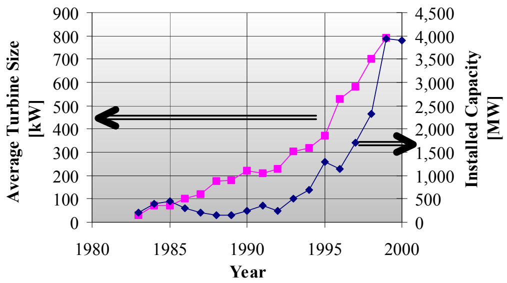

Figure 1: Size & Installation Trends (3)

OFFSHORE WIND ENERGY TODAY

Although the challenges of building large offshore windfarms will be considerable, many of the problems relating to the turbine will have previously been faced on-land, and relating to the support structure, by the offshore engineering industry. The key point will be to know how to integrate these two technologies, as it is all too easy for each branch of engineering to underestimate the complexities in the other. In fact, the combination is not always equal to the sum of the parts, both in a beneficial and a detrimental sense, hence a cost-saving opportunities may be missed and unexpected problems may be encountered during construction and operation. Avoiding unnecessary costs is especially important now when offshore wind energy aims at becoming competitive on price with traditional energy sources.

Offshore Wind Energy Technology

The wind turbines being used in current offshore projects tend to be machines designed for land-use but with modifications, such as a larger generator, a higher instrumentation specification and component redundancy, particularly of electrical systems. If the market expands as expected, machines designed for optimised performance offshore will be developed and utilised but it is not certain how they will look. On one hand, the requirements from an offshore machine differ from those on land, however the requirement for high reliability would suggest the use of well-proven turbines. Modifications may include:

larger machines, up to 5 MW or 10 MW,

faster rotational speeds than on land, where noise restrictions generally mean that the turbine operates slightly below optimum speed,

larger generators for a specific rotor size, to enable the additionally available energy to be efficiently harvested,

high voltage generation, also possible in DC instead of AC,

in the longer term, downwind machines with flexible blades or multiple rotors might become an option, but engineering effort will be needed to achieve the theoretical potential.

3.2 Grid Integration, Energy Supply & Financing

Integrating large offshore windfarms into the electricity grid may pose problems if the coastal network is weak and more advanced power control systems may be used to conform with grid connection requirements. Until now, electrical power was largely supplied by large centralised stations, which delivered a predictable power output to the consumers, adapted to varying demand patterns. If the penetration of wind energy, with an inherent stochastic behaviour, increases, additional conventional reserve power may be required to ensure the balance between production and consumption.. This may provide opportunities for the application of new technologies for electricity storage combined with more reliable models for predicting fluctuations from wind energy over longer periods.

Resources and Economics

The resources available across the offshore regions of Europe are vast, particularly in Northern Europe, and are in theory capable of supplying all electrical needs of Europe (though at an uneconomical price). In practice, offshore wind energy could become a major source of energy for several countries at a competitive price in the medium term.

So far, all offshore windfarms have been built in seas off north European coasts, where there are large flat and shallow regions a short distances away from the coast and hence suitable for development. The continental shelf at the Mediterranean Sea falls off much faster leaving little space for bottom-mounted windfarm developments unless floating wind energy can overcome its current large cost disadvantage.

3.4 Activities and Prospects

To date, eight small and medium sized offshore windfarms have been built (the first offshore plant consisted of a single wind turbine and was abandoned after a fire) and the main details are summarised in Table I. The first and largest offshore windfarms are at Vindeby (1993) and Middelgrunden (40 MW) respectively, both being located in Denmark.

Table I: Existing Offshore Windfarms (2)

Location	Year	Installed Power (MW)	Location
Nogersund (SE)	1991 (-98)	1 x 0.22 = 0.22; Windworld	in 7 m water, 250 m from shore
Vindeby (DK)	1991	11 x 0.45 = 4.95; Bonus	in 3-5 m water, 1.5 km from shore
Medemblik (NL)	1994	4 x 0.5 = 2; NedWind	in 5-10 m, 0.75 km from shore
Tunø Knob (DK)	1995	10 x 0.5 = 5; Vestas	in 3-5 m water, 6 km from shore
Dronten, (NL)	1996	28 x 0.6 = 16.8; Nordtank	in 5 m water, 20 m from shore
Bockstigen Valar, (SE)	1998	5 x 0.5 = 2.5; WindWorld	in 6 m water, 3 km from shore
Middelgrunden (DK) (7)	2000	20 x 2 = 40; Bonus	in 3-6 m water, 3 km from shore
Utgrunden (SE)	2000	7 x 1.425 = 10; Enron	in 7-10 m water 8 km from shore
Blyth (UK)	2000	2 x 2 = 4; Vestas	in 8m water 800m from shore
Yttre Stengrund (SE)	2001	5 x 2 NEG Micon = 10	

Electricity production has generally exceeded expectations and costs have steadily fallen to the point where offshore wind energy is competitive on price with many of the current onshore developments. Figure 2 illustrates this trend for a sample of studies and actual projects.

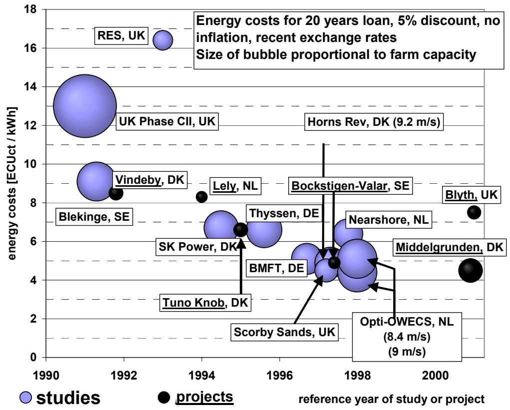

Figure 2: Reduction in Cost (6) (7)

Last year (2000), three windfarms were built, all using MW sized turbines and one, at Blyth, which is in a location facing one of the most hostile seas in Europe and will be accompanied by an extensive measurement programme.

Currently there are plans for numerous large offshore windfarms, a list is given in Table II and many countries have set ambitious targets.

Table II: Some Planned Offshore Windfarms

Location	Year	Installed Power (MW)
Horns Rev (DK)	2002	80 x 2 Vestas = 160
Lillegrunden (SE)	2002	42 x 1.5 Enercon = 63
Klasården (SE)	2002	21 x 2 NEG Mcn. = 42
Samsø (DK)	2002	22
Lübeck (DE)	2002	100
Schelde (BE)	2002	100
Egmond (NL)	2002	100
Rødsand (DK)	2003	150
Læsø Syd (DK)	2003	150
Q7 (NL)	2003	60 x 2 = 120
Schelde (BE)	2003	100
Scroby Sand (UK)	2003	70
Omø Stålgrunde (DK)	2004/5	150
13 locations in the UK	2004	540 turbines
Gedser (DK)	2006	150
Kish Bank (EI)	??	250
Arklow Bank (EI)	??	500
Rostock (D)	??	50

3.5 Social Acceptance, Environmental Impact & Politics

The experiences from current offshore projects indicate that the social acceptance is closely connected to the environmental impacts. The public concern is specially related to the impacts on birds and the visual impact and although the impacts will change somewhat, when moving further offshore, it is crucial that aspects like bird migration paths and the visual impact of offshore wind turbines in an otherwise structureless landscape are taking seriously already from the planning phase.

Furthermore, potential effects on fish, marine mammals, fauna and benthos need to be investigated, as the impacts from large scale offshore wind farms (e.g. sound emissions and electromagnetic fields from underwater cables) are currently relatively unknown.

The effect from wind turbines on radar systems is also an important issue that is currently poorly understood, and must be dealt with both in generic studies and in site-specific preinvestigations (Environmental Impact Assessments). These investigations and the planning process prior to large scale offshore projects should be as open as possible and allow local involvement.

The role that public opinion plays should not be forgotten this time; a very important difference between the countries where onshore wind energy has become widespread and where it has not become successful is in public support. Care should be taken that the detractors are not able to swing public opinion against offshore windenergy in those countries as well.

4. CONCERTED ACTION ON OFFSHORE WIND ENERGY IN EUROPE

The objectives of the project *Concerted Action on Offshore Wind Energy in Europe* [CA-OWEE] are to define the current state of the art of offshore wind energy in Europe through gathering and evaluation of information from across Europe and to disseminate the resulting knowledge to all interested, in order to help stimulate the development of the industry. The project is being funded by the European Commission and will be completed at the end of this year (2001). The knowledge gathered will be freely available through an internet site, www.offshorewindenergy.org, a printed report, and via the EWEA Special Topic Conference on Offshore Wind Energy in Brussels on December 10^{th} - 12^{th} this year (2001).

This project divides offshore wind energy into five clusters of subjects and reviews the recent history and summarise the current state of affairs, relating to:

- offshore technology, of the wind turbines and the support structures,
- grid integration, energy supply and financing,
- resources and economics,
- activities and prospects,
- social acceptance, environmental impact & politics.

The conclusions from these surveys are then used to develop recommendations for the future RTD strategy for Europe.

The project's 17 partners come from 13 countries, thus covering the majority of the European Community's coastline. The partners cover a wide range of expertise and include developers, utilities, consultants, research institutes and universities:

- Delft University of Technology, The Netherlands
- Garrad Hassan & Partners, United Kingdom
- Kvaerner Oil & Gas, United Kingdom
- Energi & Miljoe Undersoegelser (EMU), Denmark
- Risø National Laboratory, Denmark
- Tractebel Energy Engineering, Belgium
- CIEMAT, Spain
- CRES, Greece
- Deutsches Windenergie-Institut (DEWI), Germany
- Germanischer Lloyd, Germany
- ECN, The Netherlands
- Espace Eolien Developpement (EED), France
- ENEA, Italy
- University College Cork, Ireland
- Vindkompaniet i Hemse AB, Sweden
- VTT, Finland
- Baltic Energy Conservation Agency (BAPE), Poland

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