TECHNOLOGY TRENDS OF WIND ENERGY

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ABSTRACT

This paper deals with achievements of wind technology and evolution of commercial wind technology. Next it deals with a challenge of wind technologies and running up to commercial technology. In this paper are described wind turbine vertical-axis, or "egg-beater" style, and horizontal-axis (propeller-style) machines.

1. INTRODUCTION

Electricity can be generated in many ways. In each case, a fuel is used to turn a turbine, which drives a generator, which feeds the grid. The turbines are designed to suit the particular characteristics of the fuel. Wind generated electricity is no different. The wind is the fuel – unlike fossil fuels it is both free and clean, but otherwise it is just the same. It drives the turbine, which generates electricity into a grid.

Wind must be treated with great respect. The speed of the wind on a site has a very powerful effect on the economics of a wind farm: it provides both the fuel to generate electricity and the loads to destroy the turbine. This volume describes how it can be quantified, harnessed and put to work in an economics and predictable manner. The long-term behaviour of the wind is described as well as its short-term behaviour. The latter can be successfully forecast to allow wind energy to participate in electricity markets.

Technology trends investigate various design trends. As turbines have grown larger and larger, the way in which important design parameters change with size can be demonstrated and used to predict how turbines may develop in the future. For various design parameters these trends can be used to establish key challenges for the industry.

2. ACHIEVEMENTS WIND TECHNOLOGY

Modern commercial wind energy started in the early 1980s following the oil crises of the 1970s when issues of security and diversity of energy supply and, to a lesser extent, long-term sustainability, generated interest in renewable energy sources. [4]

However, wind power sceptics raised questions about:

• reliability
• noise
• efficiency
• grid impact
• visual and general environmental impact
• potential for serious contribution to a national energy supply
• cost

Initially, none of these issues could be dismissed lightly, but gradually all have been addressed.

• In larger projects with proven medium sized turbines, availability of 98% is consistently achieved. The latest large machines are also approaching that level of availability.

• Some of the early turbines were noisy – both aerodynamically and mechanically – and noise was a problem. Today, mechanical noise is practically eliminated and aerodynamic noise has been vastly reduced.

• WTs (wind turbines) are now highly efficient with less than 10% thermal losses in the system transmission. The aerodynamic efficiency of turbines has gradually risen from the early 1980s with the coefficient of performance rising from 0.44 to about 0.50 for state-of-the-art technology. The value of 0.5 is near to the practical limit dictated by the drag of aerofoils and compares with a theoretical limit of 0.59 (known as the Betz limit).

• It was often suggested that there would be major problems of grid stability with penetrations of wind energy above 10%. Now, a much more complex picture has emerged. Benefits of capacity credits, local reinforcement of grids and the ability of variable speed turbines to contribute to grid stability counteract concerns about variability of supply, mismatch with demand and the need for storage in the electrical system. In typical grid systems there may be an adverse economic impact for penetration levels above 20%, but there is no overriding technical difficulty that would limit wind energy penetration to very low values.

• Visual and environmental impacts require sensitive treatment but, Europe-wide, public reaction to operational wind farms is generally positive.

• A dismissive view of the possibility of nationally significant wind energy contributions was prevalent in the 1980s. With penetration levels of over 17% in Denmark, and around 5% in both Germany and Spain, this view is belied. Moreover, growth of the offshore market, a resource large enough to supply all of Europe's electricity, will further reinforce the significance of wind energy in the European energy supply.

• Costs of turbines per unit capacity have reduced greatly since the 1980s. This cost reduction has been achieved through both technical improvements and also through volume. Wind energy is now sometimes commercially competitive with new coal or gas power plant on good, windy sites.

3. EVOLUTION OF COMMERCIAL WIND TECHNOLOGY

The engineering challenge to the wind industry is to harness that energy and turn it into electricity – to design an efficient wind turbine (WT). In this chapter the evolution of WT technology is discussed, its present status described, and future challenges identified. The evolution of modern turbines is a remarkable story of engineering and scientific skill, coupled with a strong business spirit. In the last 20 years turbines have increased in power by a factor of 100, the cost of energy has reduced, and the industry has moved from an idealistic fringe activity to the edge of conventional power generation. At the same time, the engineering base and computational tools have developed to match machine size and volume. This is a remarkable story, and it is far from finished. Many technical challenges remain and even more spectacular achievements will result. Serious investment is needed to maximize potential through R&D (Research and Development). The use of technical jargon in this section has been kept to a minimum but technical terms inevitably arise.

4. THE CHALLENGE

The concept of a wind driven rotor is ancient, and electric motors were in profusion domestically and commercially in the latter half of the twentieth century. Making a WT can seem simple but it is a big challenge to produce a turbine that:

• Meets specifications (frequency, voltage, harmonic content) for standard electricity generation with each unit operating as an unattended power station.

• Copes with wind variability (mean wind speeds on exploitable sites range from 5 m/s to 11 m/s, with severe turbulence in the Earth's boundary layer and extreme gusts up to 70 m/s).

• Competes economically with other energy sources. The traditional "Dutch" windmill had broaden to a peak of around 100,000 machines throughout Europe by the late nineteenth century. These machines preceded electricity supply and were indeed "windmills" used for grinding grain, for example. They were always attended, perhaps inhabited and, largely, manually controlled. They were integrated within the community, designed for frequent replacement of certain components and efficiency was of little importance. In contrast, the function of a modern power-generating WT is to generate high quality, network frequency electricity. Each turbine must work as an automatically controlled independent "mini power station". It is unthinkable for a modern WT to be permanently attended, and uneconomic for it to need much maintenance. The development of the microprocessor has played a important role in realizing this situation, thus enabling cost-effective wind technology. A modern WT is required to work unattended, with low maintenance, continuously for more than 20 years.

5. RUN UP TO COMMERCIAL TECHNOLOGY

An early experiment at large-scale commercial generation of power from wind was the 53 m diameter, 1.25 MW Smith Putnam WT erected at Grandpa's Knob in Vermont, USA in 1939. This design brought together some of the finest scientists and engineers of the time (aerodynamic design by von Karman, dynamic analysis by den Hartog). The turbine operated successfully for longer than some multi-MW machines of the 1980s. It was a landmark in technological development and provided valuable information about quality input to design, machine dynamics, fatigue, sitting sensitivity, etc. The next milestone in WT development was the Gedser turbine. With assistance from Marshall Plan post-war funding, a 200 kW, 24 m diameter WT was installed during 1956-57 on the island of Gedser in the south-east of Denmark. This machine operated from 1958 to 1967 with a capacity factor of around 20%. In the early 1960s, Professor Ulrich Hütter developed high tip speed designs, which had a significant influence on WT research in Germany and the US.

1970 - 1990

In the early 1980s, many issues of rotor blade technology were investigated. Steel rotors were tried but rejected as too heavy, aluminium was meant too uncertain in the context of fatigue endurance, and the wood-epoxy system developed by the Gougeon brothers in the US was employed in a number of small and large turbines. The blade manufacturing industry has, however, been dominated by fibreglass polyester construction which evolved from a boat building background and became fully consolidated in Denmark in the 1980s. By 1980 in the US, a combination of state and federal, energy and investment tax credits had stimulated a rapidly expanding market for wind in California. Over the period 1980-95 about 1,700 MW of wind capacity was installed, more than half after 1985 when the tax credits had reduced to about 15%. Tax credits attracted an indiscriminate overpopulation of various areas of California (San Gorgonio, Tehachapi and Altamont Pass) with many ill-designed WTs, which functioned poorly. However, the tax credits created a major export market for European, especially Danish, WT manufacturers who had relatively cost-effective, tried and tested hardware available. The technically successful operation of the later, better-designed WTs in California did much to establish the foundation on which the modern wind industry is built. The former, poor quality, turbines conversely created a poor image for the industry which it has taken a long time to shake off.

1990 - Present

The growth of wind energy in California was not sustained, but there was striking development in European markets with an installation rate in Germany of around 200 MW per annum in the early 1990s and nowadays this rate is actually per month. From a technological standpoint, the significant outcome was the appearance of new German manufacturers and development of new concepts, with the introduction of innovative direct drive generator technology being particularly noteworthy. Subsequently, a huge expansion of the Spanish market has occurred, including wind farm development, new designs and new manufacturers.

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There have been gradual, yet significant, new technology developments in direct drive power trains, in variable speed electrical and control systems, in alternative blade materials and in other areas. However, the most striking trend in recent years has been the development of ever-larger WTs leading to the current commercial generation of MW machines with a new generation of multi-MW offshore turbines now appearing.

6. WIND TURBINE

A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use. Mechanical energy is most commonly used for pumping water in rural or remote locations — the "farm windmill" still seen in many rural areas of the U.S. is a mechanical wind pumper — but it can also be used for many other purposes (grinding grain, sawing, pushing a sailboat, etc.). Wind electric turbines generate electricity for homes and businesses and for sale to utilities.

There are two basic designs of wind electric turbines: vertical-axis, or "egg-beater" style, and horizontal-axis (propeller-style) machines. Horizontal-axis wind turbines are most common today, constituting nearly all of the "utility-scale" (100 kilowatts, kW, capacity and larger) turbines in the global market [3].

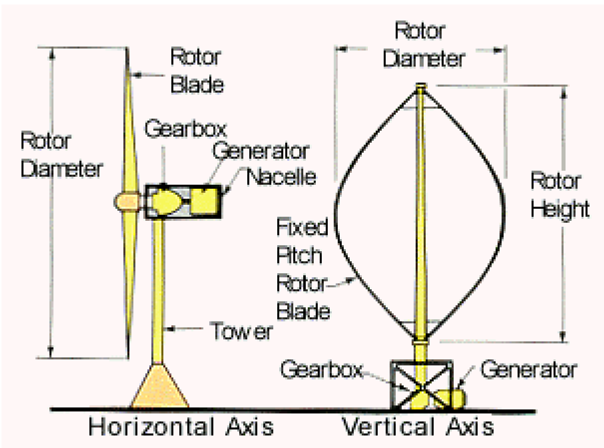

Fig.1 Wind electric turbines [3]

Turbine subsystems include:

- a rotor, or blades, which convert the wind's energy into rotational shaft energy;
- a nacelle (enclosure) containing a drive train, usually including a gearbox and a generator;
- a tower, to support the rotor and drive train; and
- electronic equipment such as controls, electrical cables, ground support equipment, and interconnection equipment.

Wind turbines vary in size. This chart depicts a variety of turbine sizes and the amount of electricity they are each capable of generating (the turbine's capacity, or power rating) Tab. 1.

	1981	1985	1990	1996	1999	2000	2004

Rotors (m)	10	17	27	40	50	71	126
Rating (kW)	25	100	225	550	750	1,650	5000
Annual MWh	45	220	550	1,480	2,200	5.600	?

Tab.1: Trends in size and capacity of wind turbines [3]

The electricity generated by a utility-scale wind turbine is normally collected and fed into utility power lines, where it is mixed with electricity from other power plants and delivered to utility customers.

7. CONCLUSION

Although the four countries studied in this article currently have 76 percent of the world's installed capacity, there are some interesting developments elsewhere. The world market for electricity generation from wind energy once again developed very dynamically in the year 2004. 8.321 MW of new capacity were added in the year 2004, marking a new record – in 2003, 8.129 MW were added. The new leader in terms of new installation is Spain with 2061 MW, thus for the first time taking over the number one position from Germany (2020 MW). Europe remains by far the leading continent in terms of installed capacity with 34,6 GW (72,7 % of the world's capacity). Germany lost its number one position in Europe and worldwide for the first time since more than a decade ago when it took the lead from Denmark. Spain, after the introduction of the improved legislation in 2004, has become the leading wind market in terms of additional capacity and represents now one sixth of the worldwide wind capacity (8.263 MW).

Many medium-sized markets bigger than 100 MW emerged in Europe in the past year. The highest growth rates (bigger than 50 %) amongst these medium European markets could be seen in Norway, Ireland, Portugal and France.

8. REFERENCES

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