WIND ENERGY DEVELOPMENTS

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ABSTRACT

At the end of the year 2000, the amount of wind energy capacity in the world was 17.7 GW. By the end of 2010, the capacity was 191 GW. That represents a compound annual growth rate of 25%. Such a high growth rate was unsustainable and the increases have declined since that time. The growth rate in 2013 was 12%, but that represented an increase of 33 GW – nearly twice the capacity that was operational in the year 2000. There are strong indications that 2014 is likely to be a higher-growth year, with the installed capacity likely to be around 45 GW.

The very rapid growth in the development of wind energy has been accompanied by an increase in the size of wind turbines (see figure 1) and steadily falling generation costs. Of all the renewable energy sources, wind is now generally the cheapest, although there are instances where geothermal can be cheaper (where steam rises close to the surface) or where favourable geography enables hydro schemes to be developed economically. At the end of 2013, there was 318 GW of wind energy in the world, approximately 700 GW of hydro, 11 GW of geothermal energy being used for the production of electricity, whilst solar photovoltaics – now developing very rapidly – accounted for 139 GW. According to the World Nuclear Association, there are now approximately 370 GW of nuclear power capacity that are operational, and so wind energy will overtake nuclear – in capacity terms - in the near future.

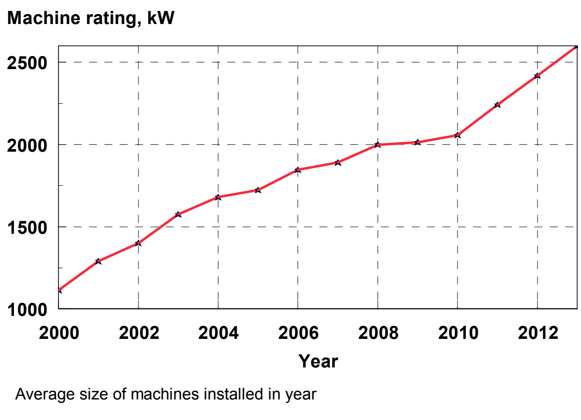


Fig. 1. The average power rating of wind turbines installed in Germany onshore from 2000 to 2012

The average load factor of wind energy, worldwide, is about 25% and so the energy-generating potential of the world's wind energy is around 700 TWh. That is enough electricity to supply the whole of Canada, and double the electricity consumption of the United Kingdom. The success of wind energy can be put down to the plentiful resources, the fact that it is a proven technology and that it can be installed quickly. Average construction time of an onshore wind farm is generally less than a year and even offshore wind farms take less than two years to construct.

BRIEF HISTORY

It was the Californian oil crisis of the late 1970s that triggered worldwide growth in wind energy. In California, subsidies for wind energy led to the construction of several thousand small machines, with rotor diameters in the range 10 to 20 m and rated powers in the range 20 to 50 kW. Other countries followed suit with similar results. In parallel with this activity, a number of governments initiated research and development programs that aimed to develop megawatt size wind turbines. The thinking behind this approach was that it would cut down the number of machines that would be required to produce quantities of electricity comparable with those from conventional power stations. Put another way, the aim was to produce the "jumbo jet" wind turbine more or less straight from the drawing board. By and large, however, few commercial machines emanated from the "large machine" research programmes, although they yielded considerable design insights. What happened instead was that commercial machine sizes gradually increased, so that 100 kW machines were available by the mid eighties, 1 MW machines by the early nineties, and by the turn-of-the-century, the largest machines had ratings around 3 MW and rotor diameters up to 70 m.

The growth of offshore wind – with the first commercial farm being commissioned in 1991 – accelerated the interest in very large machines, to the point where the largest now has a rating of 8 MW and a diameter of 164 m. Denmark commissioned the worlds first offshore wind farm, and its wind turbine manufacturers have been instrumental in developing increasingly sophisticated machines.

Figure 2 shows the relationship between rotor diameter and power rating and between rotor diameter and blade set weights. There is no universal relationship between size and rating. Machines that are designed primarily for low wind speed sites tend to have fairly low ratings, simply because full power output would only be achieved for very limited periods if the rating was high. In this case the specific rating (rated power per unit rotor area) is typically around 300 W/square metre. Machines designed for higher wind speed sites, where the maximum power can be utilised more often, may have ratings up to 600 W/square metre.

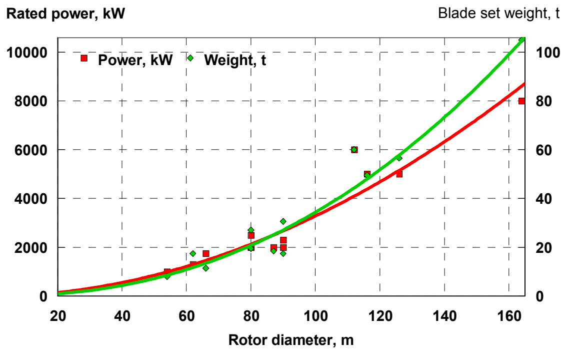


Fig. 2. The relationships between wind turbine rotor diameter and rated power, and diameter and blade set weight

The weights of the rotors of current commercial machines are typically about half those of the early machines, designed as part of state-funded research and development programmes. This is a measure of how far the industry has advanced over the last 30 years. Although the blade set weight of the164 m diameter machine is 105 tonnes, it is not eight times the weight of an 80 m machine, as a simple theory suggests. Although weights (and sometimes costs) do sometimes increase – in $/kW terms – slightly with size, there are considerable savings to be realised by using larger machines, in installation costs and internal cabling within a wind farm, for example, and so there is enthusiasm for even larger machines.

DESIGN OPTIONS

There have been a wide variety of design options over the past 30 years. More recently there has been some convergence, with the main design variations being in the drive train. In the early days two-blade machines were quite common and some of these ran "down wind", i.e. the rotor ran downstream of the tower. Nowadays, the vast majority of large commercial wind turbines have three blades, although some manufacturers do favour two blades. Methods of power control have also varied over the years. Passive "stall-control" machines were popular in the 80s. The majority of wind turbines now have pitch control, as this is essential to enable them to meet increasingly stringent grid code requirements. The relative popularity of fixed- and variable-speed concept has also changed. Fixed speed operation was common in the early years, but variable speed has gradually become more established. It confers slight benefits with higher energy capture, but perhaps its principal advantage is that rotational speeds are slow in low winds, which is when the noise from a wind turbine is likely to be most noticeable. In high wind speeds, the background noise of the wind itself is likely to mask wind turbine noise. The other concept that has gradually become firmly established is direct drive. This dispenses with the gearbox, although direct drive generators tend to be quite heavy. Approximately 50% of the machines installed in Germany in 2013 were variable speed, and over 40% had direct drive (also variable speed) [Fraunhofer Institut fur Windenergie Und Energiesystemtechnik, 2014]. However, it may be noted that there is a well-established manufacturer of direct-drive machines based there.

Drive train possibilities

The drive train is one feature of wind turbine design where the industry has not converged on a preferred solution. The "eighties" solution of an induction generator, driven by a step-up gearbox, is now becoming rare. Double-fed induction generators became popular from around 1998 onwards, and are still used, but permanent magnet generators have become more popular in the past 10 years. These are generally lighter than wound rotors and can be used in conjunction with a gearbox, or as part of a direct drive wind turbine. Because direct drive generators tend to be heavy, one intermediate option that is becoming popular, is to step up the rotor speed to, say, 500 rpm (rather than 1000 or 1500 rpm). This, it is claimed, results in a compact gearbox, with a modest step-up ratio, a compact generator and an economical solution [Halse C., 2014].

OFFSHORE WIND

Except in remote regions, the resource potential of onshore wind is likely to be constrained. This is particularly the case in Europe. The need to investigate offshore wind was therefore recognised at an early stage. Apart from the fact that it has less visual impact, another attraction of offshore wind is that wind speeds are generally higher than on land, and less turbulent. A number of desk studies were carried out in the 1980s and in 1991 the first offshore wind farm was commissioned in Denmark. It was modest in size – 10 450 kW wind turbines – and it has been operating ever since. Worldwide progress was initially slow, but accelerated during the late 1990s and now (mid-2014) 7561 MW are operational, spread across seven countries. However, 925 projects, with a total capacity of 291 GW are in operation, under construction or planned [http://www.thewindpower.net/windfarms_offshore_en.php. Accessed 5.11.2014].

Floating wind turbines

It was recognised some time ago that the potential of floating wind turbines would need to be investigated. These would enable offshore wind to be exploited in regions where the depths increases rapidly close to land and, in addition, it may facilitate access to deep water zones far offshore, where wind speeds are generally higher. In the latter case, however, the increased costs associated with higher cabling and maintenance costs far offshore, plus the cost of a floating foundation, would need to be offset by the higher energy yield that would be realised. The depth at which floating wind turbines become economically preferable cannot be quantified with any precision but appears to be between 30 m and 50 m. Potentially attractive deep-water areas close to the shore are found off California, New England, the Pacific Northwest, the Gulf of Mexico, the southwest tip of England, the Atlantic coast of Spain and several areas in the Mediterranean.

In September 2011 Japan's trade ministry announced a ¥10-20 billion ($130-260 million) project to install a 1GW floating wind development in deep waters off its northern coast by 2020. In the same month the US Department of Energy announced offshore wind Power R&D Projects with funding totalling $43M. The funding allocated to floating wind turbines is $6.44M

In the UK, the Energy Technology Institute (ETI) is investing £25m in a 5-7 MW floating offshore wind demonstrator for commissioning in 2015/16. An engineering design study for ETI by Glosten Associates, using their innovative tension leg floating platform (TLP) for an Offshore Wind demonstrator has shown that UK offshore wind energy costs could fall to below £85/MWh by the mid-2020s, with further reductions possible as the technology matures [http://www.eti.co.uk/glosten-floating-tension-leg-platform-study-for-eti-suggests-offshore-wind-energy-costs-of-below-85mwh-by-2020s].

TOWARDS 20 MW

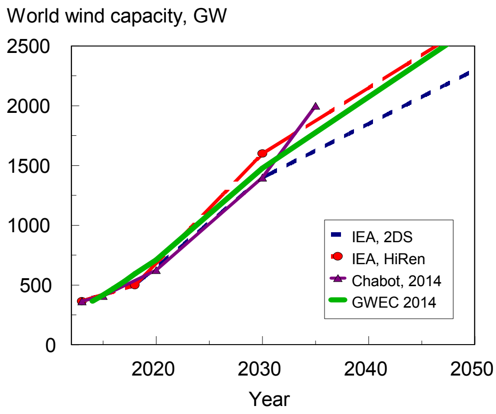
Largely driven by offshore considerations, a number of feasibility studies for machines in the 10-20 MW range have been completed, or are in progress. The "Up Wind" Project, supported by the European Commission, showed that a 20 MW, 152 m diameter wind turbine was a feasible proposition [Fichaux N., 2011]. This was followed by the Innwind project [Jensen P., 2014], which aims to build on the success of UpWind, *"to accelerate the development of innovations that help realize the 20MW wind turbine. … The overall objectives of the project are the high performance innovative design of a beyond-state-of-the-art 10-20MW offshore wind turbine and hardware demonstrators of some of the critical components. The progress beyond the state of the art is envisaged as an integrated wind turbine concept with:*

- *A light weight rotor*
- *An innovative, low-weight, direct drive generator*
- *A standard mass-produced integrated tower and substructure that simplifies and unifies turbine structural dynamic characteristics at different water depths"*

The project has a €19 million budget and 27 participants and will run until 2017.

In parallel with InnWind, the European Energy Research Alliance (EERA) has initiated the AVATAR project. Its main goal is the development and validation of advanced aerodynamic models, to be used in integral design codes for the next generation of large-scale wind turbines (up to 20MW).

THE FUTURE



There is a good consensus between the four projections, with all suggesting that 500 GW will be reached by 2020 and 1000 GW by 2025, or shortly after. As the industry is continuing to innovate, generation costs are expected to continue falling. Its low carbon credentials should ensure that it remains an attractive choice for electricity generation [Chabot B., 2014, GWEC 2014, IEA Technology Roadmap, 2013].

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