A Brief History of the Wind Turbine Industries in Denmark and the United States

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Abstract

The history of wind-power used to produce electricity dates back to the late 19th century and early 20th century when the two pioneering countries in the industry, Denmark and the United States, developed the first electricity-producing wind turbines. Ever since then both countries have invested countless resources in development, which should have lead the way to company formations, and continuous industry development.

A follow-up paper will attempt to explain why the development of the wind turbine industries in the U.S. and Denmark has taken such different paths.

The World Market Today

The global wind industry has been growing at a rate above 40% per annum during the past five years with the top markets being Germany, Spain, Denmark and the US. The production of wind turbine-generated electricity is hence drastically increasing and some countries have now reached a double-digit (percentage) coverage of their electricity consumption – Denmark being the leading country with 13-14% compared to only 2% in the US. The growth, however, is concentrated in a

few countries and globally the role of wind-generated electricity is still insignificant, covering only 2 parts per million of global consumption.

The industry is nevertheless starting to experience globalization as several of the major companies have promoted serious international growth, establishing manufacturing facilities, sales offices, alliances and joint ventures around the world in order to break into new, and even established, markets. Wind energy employed some 60,000 people worldwide in 2001, of which 45,000 were in the European Union. (Krohn 2002).

The electricity is supplied from almost 50 different countries although the greater part is provided from wind turbine plants in Germany, Spain, the US and Denmark (measured in kilowatts, Denmark is responsible for more than 50% of the world's production of wind energy).

On the supply-side there are roughly 25 larger manufacturers of wind turbines in the world. Of these 25 the top ten manufacturers form a strategic group providing approximately 95% of the total recorded installation. The four leading companies in the top ten – Vestas Wind Systems (DK), Enercon (GE), NEG Micon (DK) and Gamesa (SP) – together account for two thirds of the total supply and hence dominate the world market for wind turbines.

Danish Vestas Wind Systems A/S has for years maintained its position as the world's largest manufacturer of wind turbines and leads this top ten cluster of companies. Together with the two other Danish top ten manufacturers, NEG Micon and Bonus, they now account for approximately 45% of the US$4.5 billion global wind turbine market making tiny Denmark, with a population of only 5 million, the world's top manufacturer and exporter of wind turbines. The German manufacturers Enercon, Nordex and Repower together form the second largest cluster in the strategic group with approximately 30% of the market, followed by the Spanish cluster of Gamesa, Made and Escotecnia with a total market share of approximately 14%. The only American manufacturer in the top ten, GE Wind, accounts for 9% of the world market leaving only 5% of the world market to the remaining 15 manufacturers. In a second, follow-up paper, we will examine some of the reasons why the industries in these two countries have developed differently.

Development

The most obvious influence on 20th century wind power has been the ever-increasing use of electricity, particularly in the industrialized countries, but also around the rest of the world. But this started with a look to the past.

The discovery of wind-power generated electricity dates back to the end of last century and has encountered many ups and downs in its more than 100-year history. In the beginning, the primary motivation for basically all the research in wind-power was to strengthen the mechanization of agriculture through local-made electricity. With the electrification of the industrialized world, however, the

role of wind-power decreased, as it could not compete with the fossil-burning power stations, which showed to be far more competitive in providing electrical power on a large scale.

Lack of fossil fuels during World War I and later World War II created an awareness of the great dependence on fossil fuels and gave wind-power renewed attention. The interest, however, was short-lived. The prices for wind-powered electricity were still not competitive and politically nuclear power was given more attention and hence more research funds. It took two oil crises in the 1970s with supply-problems and price fluctuations on fossil fuels before wind-power once again was put on the agenda. And it was these issues confronting many countries in the 1970s which jump-started a new era for wind power and spurred the development of a global industry which today is characterized by relatively few but very large wind-turbine manufacturers – primarily from Denmark, Germany, Spain and the US.

The Birth of the Wind Turbine Industry

Energy from wind has been utilized for many centuries in the traditional agricultural societies around the world as supplement to the muscle power of humans and animals. This historic section of the early industry and its development will nevertheless only cover the period from when scientists in Denmark and the U.S. first experimented with transforming wind into electricity and the development of wind generated electricity in the two respective countries.

Denmark

The Danish climate is due to the country's long coastline characterized by consistent and strong winds. With no other natural energy sources such as coal, water falls for hydropower, etc. it therefore seems almost natural that Denmark became one of the first countries in which scientists and engineers started a dedicated effort to experiment with and implement wind technology as basis for electrification.

The fairytale story of the Danish wind turbine industry started when physicist Poul La Cour – a professor in natural science at the Askov Folk High School – and a team of scientists built the first wind turbine in 1891 funded by the Danish government. (Krohn 2002) La Cour was drawing on the results of two contemporary Danish engineers and scientists, H. C. Vogt and J. Irminger, who together with the American P. S. Langley participated in formulating modern theory on aerodynamic lift and drag. (Andersen 1999) The purpose was to experiment with wind power for the production of electricity.

In the beginning, the test-mill produced electricity to the school and later to the people of the town of Askov. La Cour's dream, however, was to create locally produced electricity for the agriculture and all around Denmark 30-something small village-power stations were soon built. By the 1930s Denmark was well ahead of many other countries and wind turbines were traditional in the countryside in Denmark even before World War II. At Askov Folk High School it even became possible to

study wind turbines where La Cour gave courses in wind energy for Danish “wind electricians”. (Krohn 2002) La Cour and one of his students, Lykkegaard, soon became some of the most prominent manufacturers in Denmark – maybe even in the world – as there was no real international competition at that time.

Wind power was nevertheless soon ousted by electricity from central coal-burning power stations and the national high-voltage net, which was being built at that time. Before long wind power became less appealing compared to other energy sources but was later given a new chance – first during World War I and even more so during World War II when temporary shortages of fossil fuels (coal and oil) led to higher energy costs. Wind power research continued, though at a much less-publicised rate than previously. (Andersen 1999)

During World War I in 1914-1918 there were approximately 250 electricity-producing wind turbines in Denmark, of which 120 were connected to power stations. Following the war, however, the interest diminished again and by 1920 only 75 power stations used wind turbines and by 1940 the number had been further reduced to 25.

When World War II became a reality in 1940, the country was once again faced with scarcity of oil and coal. At this point in time Danish industrial wind power developments were undertaken especially by the companies Lykkegaard Ltd. and the cement group F. L. Smidth & Co., which, in cooperation with the aircraft company Kramme & Zeuthen, developed a new type of wind turbine with aerodynamic wings and a tower of concrete with an output of 40-70 kW. (Vindmøller før og nu)

In spite of several attempts from small entrepreneurs such as the above-mentioned, electricity-producing wind power never really became generally accepted. But the supply deficit and lack of energy sources did leave many impressions and thoughts for the future and the Danish power stations set up a committee for wind power, whose task was to look into the potential role of wind energy in the future.

The United States

Wind energy as a resource is also abundant in many parts of the U.S. – especially along the east coast, the Appalachian Mountain chain, the Great Plains and the Pacific Northwest and the extraction of power from the wind here also dates back to before the turn of the century.

The first use of a large wind turbine to generate electricity was a system built in Cleveland, Ohio, in 1888 by Charles F. Brush. The Brush machine was the first wind turbine to incorporate a step-up gearbox in order to turn a direct current generator at its required operational speed. Despite its relative success in operating for 20 years, the Brush wind turbine demonstrated the limitations of the low-speed, high-solidity rotor for electricity production applications. (Dodge 2002)

During the 1920s, the two dominant rotor configurations (fan-type and sail) had both been tried and found to be inadequate for generating significant amounts of electricity. A shift was therefore undertaken and the further development of wind generator electrical systems in the United States was inspired by the design of airplane propellers and (later) monoplane wings.

The first small electrical-output wind turbines simply used modified propellers to drive direct current generators. By the mid-1920s, 1 to 3-kilowatt wind generators developed by companies like Parris-Dunn and Jacobs Wind-electric found widespread use in the rural areas of the Midwestern Great Plains. They had two or three thin blades, which rotated at high speeds to drive electrical generators. These wind turbines were installed to provide electricity to farms beyond the reach of power lines and were typically used to charge storage batteries, operate radio receivers and power a light bulb or two.

Wind turbine generators hence achieved a measure of technical and economic practicality in rural and remote areas of the country during the 1920s and in the 1930s and 1940s, hundreds of thousands of electricity producing wind turbines were built in the U.S. The wind turbine industry in North America remained very active into the 1930s. During this decade, however, the combination of demand of farmsteads for ever larger amounts of power and a major economic depression spurred the U.S. federal government to stimulate the depressed rural economies by extending the electrical grid throughout those areas. The lower cost of electricity produced by a central utility plus the greater reliability led to the rapid demise of the home wind electric generator and therefore began a slow decline from which the wind turbine industry in North America never fully recovered.

The largest wind turbine built before the late 1970's was a 1250 kW machine built on Grandpa's Knob, near Rutland, Vermont, in 1941. The concept for this turbine started in 1934 when an engineer, Palmer C. Putnam, began to look at wind electric generators to reduce the cost of electricity to his Cape Cod home. In 1939, Putnam presented his ideas and the results of his preliminary work to the S. Morgan Smith Company of York, Pennsylvania. They agreed to fund a wind-energy project and the Smith-Putnam wind turbine experiment was born, involving a team of scientists who designed, built and operated the world's first megawatt-size wind power plant (corresponding to the output of the wind turbines of today). (Johnson 2001)

Between 1941 and 1945 the Smith-Putnam machine, which was connected into the Central Vermont Public Service Corporation's network, accumulated about 1100 hours of operation. More would have been accumulated except for the problem of getting critical repair parts during the war. In 1945 one of the blades broke off near the hub, apparently as a result of metal fatigue and hence due more to inadequate design than to technological limitations. The project was reviewed and was determined to be a technical success. The economics, however, did not justify building more machines at that time. The project, however, advanced the field of wind power engineering from small DC generators and water pumps to large AC units capable of integration into electrical supply systems.

In spite of the fact that the jump in scale was too great for the materials available at that time Palmer Putnam's 1.25-megawatt wind turbine became one of the engineering marvels of the late 1930's. (Johnson 2001)

The gradual extension of electrical utility networks and the availability of low cost fossil fuels lead to the abandonment of wind turbines by the 1940s. The early success of the Midwest wind turbines, however, had set the stage for the possibility of more extensive wind energy development in the future.

The 1950s

While the market for new small wind machines of any type had been largely eroded in the United States by 1950, the use of mechanical and electrical system continued throughout Europe. The development of bulk-power, utility-scale wind energy conversion systems was undertaken in several countries and although research showed that large-scale wind turbines actually would work, it failed to result in a practical large electrical wind turbine.

Denmark

After World War II the Danish interest in wind energy diminished but Johannes Juul, a Danish engineer at a power utility and former student at the Askov Folk High School, started a R&D program on wind energy utilization. He was one of the more pioneering wind turbine inventors and his R&D effort formed the basis for his design of a modern electricity producing wind turbine – the well-known Gedser machine which was installed in 1959. The design was much less mechanically complex than the American Smith-Putnam design. In fact, it was not that far removed from Poul La Cour's 1920-era wind turbine (a fact that worked to its advantage) and as it turned out the three-winged design became the basis for the mills developed in the 1970s as we know them today. (Krohn 2002)

With its 200kW capacity, the Gedser-mill was the largest of its kind in the world at that time and it was in operation for 11 years without maintenance. The last five years however, the Danish Association for power stations, which had participated in the funding and building of the mill, concluded that wind turbines – considering the low oil prices – were too expensive and therefore uncompetitive. The association lost interest and suspended the wind power program, referring to the uncompetitivesness of wind energy. In reality, however, the interest had shifted to nuclear power as a potential source of energy and research funds were hence transferred to the nuclear test plant of Risø, which was inaugurated in 1958. (Krohn 2002)

The Gedser-machine was nevertheless refurbished in the mid 1970’s at the request of NASA, which needed measurement results for a new ambitious U.S. program for the construction of large wind turbines and the wind turbine ran for another 3 years. (Krohn 2002)

Post war activity in Denmark largely dictated the two major horizontal-axis design approaches that would emerge when attention returned to wind turbine development in the early 1970s. The Danes refined the simple Gedser-mill design, utilizing advanced materials, improved aerodynamic design, and aerodynamic controls to reduce some of its shortcomings.

The United States

By the early 1950s the extension of the central power grid to nearly every American household, via the Rural Electrification Administration, had almost eliminated the market for wind turbines. The technical results of the Smith-Putnam wind turbine had nevertheless caused Percy H. Thomas, an engineer with the Federal Power Commission, to spend approximately 10 years in a detailed analysis of wind power electric generation. Thomas used economic data from the Smith-Putnam machine and concluded that even larger machines were necessary for economic viability. He designed two large machines in the size range of 6500kW and 7500 kW.

In 1951, The Federal Power Commission approached Congress for funding a prototype of this machine. At that time, however, the Korean War was starting, and Congress chose not to fund the prototype and the project was later canceled. This basically marked the end of American wind power research for more than twenty years until fuel supplies again became an immediate problem. (Johnson 2001)

The Modern Wind Industry

Modern wind energy use began in the late 1970s as part of a response to the oil crises in 1973 and 1979, which affected the entire western world and turned out to have a great impact on the wind turbine industry.

The oil crisis in the 1970s

The pessimism from the years after the two World Wars did not bear comparison with the reality – the expected lack of oil and coal failed to appear. Instead the prices of oil fell in the 1960s. Energy consumption was increasing drastically as was the general growth and wealth in the industrialized countries. It therefore took a serious energy crisis before wind power once again was put back on the agenda.

This turn-around came in October 1973, when Egyptian troops crossed the Suez Canal entering Sinai, which Israel had occupied during the 6-day war in 1967. A war in the Middle East had started and this time oil was used as a weapon in the conflict. Throughout the 1950's and 1960's OPEC (Organization of the Petroleum Exporting Countries) had gradually gained more and more control of its resources of oil at the cost of "the seven sisters" – the large American-dominated oil companies – and it subsequently decided to raise oil prices and introduced an oil embargo on countries supporting Israel. The resulting supply problems and rising prices not only caused downward mar-

ket conditions in the Western part of the world but also proved just how vulnerable and dependent these countries had become on the import of energy. Wind power was therefore soon back on the lips of everyone – politicians, researchers, manufacturers and the public – and this time it was here to stay.

From an experimental stage of turning wind energy into electricity in the early 1970s, a new industry for producing standardized wind turbines gained foothold in the beginning of the 1980s and since then the industry has developed rapidly throughout the 1980s and the 1990s. The renewed interest for using wind energy commercially is thus not more than twenty-five years old and it is during this period that the sheep in the industry have been separated from the goats.

Future Research

In a follow-up paper, the authors of this paper will attempt to explain why the wind turbine industries in the United States and Denmark have taken such divergent paths. In order to identify the main factors that may have influenced the two very different paths that the wind power industry took in the two countries, we will employ Michel Porter's "industry Diamond". Porter believes that technological development and competitive advantages are a result of "improvement and innovation in an industry that are never ending processes, not a single, once-and-for-all event." The Diamond serves to explain the long-run development of a country's international competitive position, which is created on the basis of the individual nations own unique characteristics. The model is probably the best-known analytical tool for understanding the development and the attractiveness of an industry and entails those values, which according to Porter's research are important in gaining a national competitive advantage.

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