Wind Energy Conversion System: The Past, The Present And The Prospect

Kajogbola R. Ajao & Modupe R. Mahamood

Department of Mechanical Engineering, University of Ilorin, Ilorin, Nigeria
Email: ajaomech@unilorin.edu.ng , mahamoodmr@unilorin.edu.ng

Abstract: Wind energy has matured to a level of development where it is ready to become a generally accepted utility generation technology. Wind turbine technology has undergone a dramatic transformation in the last decades, developing from a fringe science in the 1970's to the wind turbines of the 1990's, utilizing the latest in power electronics, aerodynamics and mechanical drive train design. The developmental stages of wind energy conversion and utilization over the years was reviewed and given the advanced state of wind turbine technology, availability of wind resources, the modularity of wind electric generators and an expected increase in demand for environmentally friendly energy sources, it is expected that wind energy will become a significant component of energy supply portfolio in the near future. [The Journal of American Science 2009;5(6):17-22].(ISSN:1545-1003).

Keywords: Wind energy, Wind turbine, power electronics, aerodynamics, drive train, energy portfolio.

1. Introduction

The precise date when man first used a machine to assist him in his daily work would be virtually impossible to determine. However, it seems clear that the earliest machines were based on the principle of rotation as a means of providing continuous motion for routine tasks such as grinding corn or pumping water. Thus, there were the mills, driven by animal or man-power, in which the rotating shaft was vertical and driven by a long horizontal beam, fixed to it, and pulled or pushed around by the animal walking round in a circular path (Golding, 1976).

Wind energy has been used for a long time. The first field of application was to propel boats along the river Nile around 5000B.C. By comparison wind turbines technology is a fairly recent invention. The first simple windmills were used in Persia as early as the 7th century for irrigation purposes and for milling grains.

In Europe, it has been claimed that the crusaders introduced the windmills around the 11th century. Their constructions were based on wood. In order to bring the sails into the wind, they were manually rotated around a central post. In 1745, the fantail was invented and soon became one of the most important improvements in the history of the windmill.

The modern concept of windmills began around the industrial revolution. Millions of windmills were built in the United States during the 19th century. While the industrial revolution proceeded, the industrialization sparked the development of large windmills to generate electricity. Pour La Cour developed the first electricity generating wind turbine (Anders, 2005).

The earliest horizontal-axis windmill to use the principles of aerodynamic lift instead of drag may have been introduced in the 12th century. These horizontal-axis sail turbines were allowed to run at varying speeds, limited only by braking or furling to control their speed during storms. In the over seven hundred years since the first sail-wing turbine, designers discovered many of the key principles of aerodynamic without understanding the physics behind them. It was not until the 19th century that these principles began to be clearly understood (Carlin et. al, 2001).

In the early 19th century, the classic American water pump was introduced. The need for this machine was driven by the phenomenal growth of agriculture in the American Midwest, beginning with the opening of the Northwestern Prairie States in the early 1800's. More than a million of these machines dotted the Midwest and West starting in the early 1850's. Even now, these multi-bladed farm windmills can be seen throughout the western United States and Canada, where the energy and storage requirements for providing drinking water for cattle are well matched to the wind powered water pump, the storage capacity of the associated stock tank, and the wind statistics of the Great Plains.

These machines use the most rudimentary airfoils and are allowed to rotate proportionally to wind velocity. For the purpose of direct mechanical water pumping, this variable-speed operation works effectively. Even though the American water-pumping design gives up something by its dependence on a flat-plate airfoil, its simplicity, ease of construction and reliability still make it ideal for its intended purpose.

In 1925 Marcelleus and Joseph Jacobs began work on the first truly high-speed, small-size, affordable battery charging turbine. Thousands of their 32-volts and 110-volts direct current machines were manufactured. This machine was followed by others such as wind charger. They could be set up easily and require little maintenance, if any. All of these machines were allowed to run at variable speed. Even after alternating current utility power had begun to spread through cities and towns, Sears Roeback Company and other manufacturers distributed a wide range of products designed to run on direct current to satisfy the needs of remote farms and ranches using batteries and variable-speed direct current turbines (Carlin et. al, 2001).

In the late 30's and then in 1941, Americans started planning a megawatt-scale wind turbine generator using the latest technology. The result of this work was the 1.25MW Smith-Putnam wind turbine. This was the largest wind turbine ever built then and it kept its leading position for forty (40) years thereafter.

With the introduction of the steam engine in the 18th century, the world gradually changes its demand for power to techniques and machines based on thermodynamic processes. Especially with the introduction of fossil fuel (coal, oil and gas) the advantages of these machines became obvious.

Firstly, steam engines, gas turbines, and oil and gas based engines are much more compact and can provide power at a much larger scale than necessary for water pumping and grinding. Secondly, they can be located independent of the streaming water or good wind sites. Finally, these machines provided a more reliable source of power than wind turbines (Andersen).

Therefore, the importance of wind energy as a power source decreased during the 19th century and especially during the present century. Though, in some parts of the world wind energy prolonged its utility. In countries with populations scattered over large areas, such as the Americas, Australia, and Russia, wind power continued to contribute to the power needed, for example in farming. With the electrification of the industrialized world the role of wind power decreased. Fossil fuels showed to be more competitive in providing electrical power on large scales.

Meanwhile, the traditional wind rose (the multi bladed wind turbine) used in the farmland all over the world was still further developed and refined. The wood used in most parts of these machines was replaced by iron and steel. Lattice steel towers as well as steel blades were introduced. This transformation from wood to steel did not appear over night but went on for some decades, and contributed to the optimization of the wind turbines. In the 1920's and 1930's the French F.M Darrieus and the Finnish S.J Savonius designed and tested new concepts for vertical-axis wind turbines.

In the 1920's the German professor Albert Betz of the German Aerodynamic Research Centre in Gottingen made some path-breaking theoretical studies on wind turbines in the light of modern research by determining the coefficient of performance of a wind turbine to be 0.593 and known as the Betz limit. Also in the 1920's H. Glauert contributed with an aerodynamic theory for wind turbines. Both of these theoretical contributions are still the foundation of today's rotor theory.

2. Wind Power in Denmark

The early dissemination of information on windmills all over Europe also involved Denmark. Here the first windmill was mentioned in 1259 and it was placed in the village of Flong between Roskilde and Copenhagen [4]. With the fossil fuels and the electrification, the development followed the same pattern as in the rest of Europe, but in countries without any domestic fossil resources such as Demark, wind energy continue to contribute to the supply of energy. First of all with the classical purposes in the farm land as pumping water and grinding grain.

In 1916 alone, one thousand, three hundred (1300) new ones were built to provide power to threshing machines, grinding mills, and for water pumping. With no other realized natural energy sources (no water falls for hydropower, no coal, etc) it may seem natural that Denmark became the first country in which scientists and engineers began a dedicated effort to implement wind technology as a basis for electrification. This started in 1891, when Poul La Cour and a team of scientists built a test windmill, funded by the Danish government at Askov Folk High school.

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 which will be discussed in later chapter.

By 1918, as a result of La Cour's work, a fourth (about 120 in number) of all Danish rural power stations used wind turbines for power generation. Most machines had a rated capacity of 20-35kW.

After World War I, with a sufficient supply of fossil fuel, these machines were rapidly outdated, and in 1920 only seventy-five turbines were left. But immediately after World War II, J. Juul, a Danish engineer at a power utility, SEAS, started a Research and Development programme on wind energy utilization. This research and development (R&D) effort formed the basis for Juul's design of modern electricity producing wind turbine-the well-known 200kW Gedser machine. The Gedser machine was installed in 1959 and was in operation until 1967.

In 1977, when data for large wind turbine were badly needed, the refurbished Gedser machine was used for a measurement programme, which was co-funded by the U.S Department of Energy. This programme was carried out by Risϕ National Laboratory and formed Risϕ's entrance to wind turbine research and development. Besides, a tradition in wind turbine R& D, Risϕ also draw on a tradition on boundary layer meteorology and wind climate studies.

The studies of aerodynamic and wind tunnel experiments performed by Irminger by the turn of the century was continued at the Technical University of Denmark by Professor Nϕkketved, Martin Jensen and Niels Franck. Their path-breaking research on wind climate, model laws, terrain roughness, and shelter effects formed the scientific platform for European wind Atlas used for wind resource estimation. This work was initiated in the late 1970's. The Awakening green movement in the western societies and especially the oil embargoes of 1973 and 1979 set the stage for the present era of wind power.

3. Wind Power in United States

Charles F. Brush was the first to use a large wind turbine to generate electricity (Robert et. al, 2004). The system was built in Cleveland, Ohio in 1888. 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 over 20 years, the Brush wind turbine demonstrates the limitations of the low-speed, high-solidity rotor for electricity applications.

During the 1920's, the two dominant rotor configurations (fan-type and sail) had both been tried and found to be inadequate for generating significant amount 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.

The first small electrical-output wind turbines simply use modified propellers to drive direct current generators. By the mid-1920's, 1 to 3 kilowatts wind generators developed by companies like Parris-Dunn and Jacobs wind-electric found widespread use in the rural areas of the Midwestern Great Plains of USA. 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 generator hence achieved a measure of technical and economic practicality in rural and remote areas of the United States during the 1920's and 1930's. In the 1940's hundred of thousands of electricity producing wind turbines were built in the United States. The wind turbine industry in North America remained very active into the 1930's. During this decade, however, the combination of demand of farmsteads for ever large amounts of power and a major economic depression spurred the United States to stimulate the depressed rural economics 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 industry never fully recovered.

The largest wind turbine built before the late 1970's was a 1250kW 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 generator 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. Agreement was reached 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 (Dodge).

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 World War

II. In 1945 one of the blades broke off near the hub, apparently as a result of metal fatigue and hence due to inadequate design than 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 direct current generators and water pumps to large alternating current units capable of integration into electrical supply systems.

The gradual extension of electrical utility networks and the availability of low cost fossil fuels led to the abandonment of wind turbines by the 1940's. By the early 1950's 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 7500kW.

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

4. Wind Power in Nigeria

Nigeria is blessed with abundant fossil fuel (oil and gas) and the Government investment in power generation had been mainly restricted to thermal coal plants, gas plants and hydro power stations. Adegoke and Anjorin (1996) investigated the prospects of wind energy utilization in Nigeria by analyzing available wind data for Akure, Bauchi and Port Harcourt and observed that the average wind speed measured at 10metres height above the ground for Bauchi is 4.78m/s, Port Harcourt is 2.56m/s and that for Akure is 0.76m/s. It was concluded that Bauchi favours the installation of wind turbines more than Port Harcourt and Akure and that the variation of annual mean wind speed is much lower for Port Harcourt than it is for Bauchi implying that wind turbines installed in Port Harcourt would function more regularly over several years.

Wind speeds of not less than 2.22m/s have been found to be favourable for uses of windmills in northern Nigeria although this may strictly apply to the type of windmill tested. It has also been reported that most windmills would not start at wind speeds less than 3m/s (Ejieji, 2006).

The National Energy Commission of Nigeria (NECN) is presently leading Research and Development (R&D) efforts in developing indigenous technology in wind energy conversion systems.

5. Wind Power utilization today

The expected global shortage of oil and coal after World War II did not happen. Instead the prices of oil fell in the 1960's. 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 Organization of Petroleum Exporting Countries (OPEC) had gradually gained more and more control of oil 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 market conditions in the Western world but also proved just how vulnerable and dependent these countries had become on the import of oil. Wind power was therefore soon back to reckoning.

Table 1: World Grid-Connected Wind Capacity (MW) Data (Adapted from IEA, Wind Power Monthly, April, 2001)

Cumulative(MW)	**1980**	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
United States	10	1,039	1,525	1,770	1,794	1,741	1,890	2,455	2,554	4,240	4,685	6,374
Germany	2	3	60	1,137	1,576	2,082	2,874	4,445	6,095	8,100	11,994	14,609
Spain	0	0	9	126	216	421	834	1,539	2,334	3,175	4,825	6,202
Denmark	3	50	310	630	785	1,100	1,400	1,752	2,338	2,417	2,889	3,110
Netherlands	0	0	49	255	305	325	364	416	447	483	693	912
Italy			3	22	70	103	180	282	427	682	788	904
United Kingdom	0	0	6	193	264	324	331	344	391	477	552	649
Europe	5	58	450	2,494	3,384	4,644	6,420	9,399	12,961	16,362	23,308	28,706
India	0	0	20	550	820	933	968	1,095	1,220	1,426	1,702	2110
Japan	0	0	1	10	14	7	32	75	121	250	415	686
Rest of the World	0	0	6	63	106	254	315	574	797	992	1,270	1,418
World Total	15	1,097	2,002	4,887	6,118	7,579	9,625	13,598	17,653	23,270	31,128	39,294

From an experimental stage of turning wind energy into electricity in the early 1970's, a new industry for producing standardized wind turbines gained foothold in the beginning of the 1980's and since then the industry has developed rapidly throughout the 1980's and the 1990's.By the end of 1996 a total of 6200MW grid connected wind turbine capacity was installed around the world.

Today, wind energy is the fastest growing energy technology in the world. The world wind energy capacity installations have surged from under 2000MW in 1990 to the present level of approximately 39,500MW. It is expected that the wind turbine capacity will rise to 230GW by the year 2020 judging from the current attention been given to it.

There has been a concerted effort over the last decade to raise the level of technology in small wind turbines led by groups such as the American Wind Energy Association (AWEA), and the National Wind Technology Centre (NWTC) in Colorado which is part of the U.S Department of Energy's National Renewable Energy laboratory (NREL) among others (Andrew, 2005).

6. The future of wind energy system

In the years to come, the prime resource for generation of wind power will not be wind but windy sites. With only limited sites suitable for wind power generation available, it makes better sense to develop technologies, which will increase the efficiency of wind electric generators.

The developments in turbine technology coupled with optimization techniques will lead to higher energy densities. Also it is expected that in future the power quality issues in grid interfacing wind electric generators will be addressed and power quality devices will be inbuilt into the turbines.

The global wind energy installed capacity has increased exponentially over a 25-year period, and in the process the cost of energy (COE) from wind power plants has been reduced by an order of magnitude. Wind energy installations in the United States have grown during the past decade from about 1800 MW in 1990 to more than 6,000 MW at the end of 2003(Musial et. al, 2004).

Offshore wind turbines have a number of advantages over onshore ones. The size of onshore turbines is constrained by capacity limitations of the available transportation and erection equipment. Transportation and erection problems are mitigated offshore where the size and lifting capacities of marine shipping and handling equipment still exceed the installation requirements for multi-megawatt wind turbines.

The visual appearance of massive turbines in populated areas may be undesirable. At a sufficient distance from the coast, visual intrusion is minimized and wind turbines can be larger, thus increasing the overall installed capacity per unit area. Similarly, less attention needs to be devoted to reduce turbine noise emissions offshore, which adds significant costs to onshore wind turbines. Also, the wind tends to blow faster and more uniformly at sea than on land. A higher, steadier wind means less wear on the turbine components and more electricity generated per square meter of swept rotor area can be integrated to the national grid.

Onshore turbines are often located in remote areas, where the electricity must be transmitted by relatively long power lines to densely populated regions, but offshore turbines can be located close to high-value urban load centers, simplifying transmission issues.

On the negative side of offshore development, investment costs are higher and accessibility is more difficult, resulting in higher capital and maintenance costs. Also, environmental conditions at sea are more severe: more corrosion from salt water and additional loads from waves and ice.

And obviously, offshore construction is more complicated. Despite the difficulties of offshore development, it holds great promise for expanding wind generation capacity.

7. References

[1]. Golding E.W (1976). The generation of electricity by wind power. E&F.N SPON Ltd, London.

[2]. Anders A (April, 2005). "Aerolastic Simulation of Wind Turbine Dynamics". Ph.D. Thesis, Department of Mechanics, Royal Institute of Technology, SE-10044 Stockholm Sweden.

[3]. Carlin P.W, Laxson A.S and Muljadi E.B (February 2001). "The History and State of Art of Variable-speed Wind Turbine Technology". NREL/TP-500-28607.Technical Report.

[4]. Andersen, Per Dannemand. "Review of Historical and Modern Utilization of Wind Power". Available at www.risoe.dk/rispubl/VEA/dannemand.html, accessed on 12th February 2007.

[5]. Robert D.G, Brandstrup L and Vestergaard J (November, 2004). "A Brief History of the Wind Turbine Industries in Denmark and the United States". Conference proceedings: Academy of International Business (Southeast USA Chapter) Pp.322-327.

[6]. Dodge D.M. "Illustrated History of Wind Power Development - 20th Century Development". 2002. Available at http://telosnet.com/wind/20th.html, accessed on 17th April, 2007.

[7] Adegoke C.O. and Anjorin A.S (October 1996). "Wind as an alternative energy source". J.Sci.Engr.Tech 3(2), pp. 511-524.

[8] Ejieji C.J (2006). "An Evaluation of Wind Energy Potentials in Ilorin, Kwara State of Nigeria". Ife Journal of Technology. Vol.15 (2), pp. 27-35.

[9] Andrew K.W (September, 2005). "Aspects of the Aerodynamics and Operation of a Small Horizontal Axis Wind Turbine". Unpublished Ph.D. Thesis, Department of Mechanical Engineering, University of Newcastle, Australia,

[10] W. Musial and S. Butterfield (June 2004). "Future for Offshore Wind Energy in the United States". NREL/CP-500- 36313.

3/11/2009