I J C T A, 9(6), 2016, pp. 2819-2826 ISSN: 0974-5572

Comprehensive Review on the Wind Energy Technology

Shahrukh Adnan K.[1], Rajprasad K.R.[2], Aravind C.V.[3], Wong Y.W.[4], Selima Shahnaz Geo.[5] and Low Jay See[6]

ABSTRACT

This paperpresents a comprehensive review on the wind energy technology in the past two decades. If presents some of the most important literaturesof wind energy technology in the way it is used for energy harvesting. The emphasis is placed on reviewing literature in wind power history and wind turbine types which have been developed gradually over time.The beginning of wind technology followed by a steady yet progressive expansion of wind industry is given in the chronological order.

Keywords: Wind Power History, Vertical Axis Wind Turbine, Classification, Turbine Generator.

1. INTRODUCTION

Wind energy is one of the oldest ways for energy solutions through mechanical means of control. The highly unreliable wind speed and the deep fluctuations in the conversion mechanisms push a biggest challenge in the energy conversion. Also the dynamic nature of production of energy rather like the static way of energy conversion in solar energy makes wind to be second next source than the solar technology. The choice of new types of power control strategy the development of electromechanical devices read the interest on this technology in the past decade. In order the look into the road map of the wind energy technology start from the initial days to the state of art today makes an interesting journey. The main idea of this paper is to get the overview of the gradual development towards wind power technology that has happened over years. At the same times, all the work that have been carried through in recent years along with the ancient time have been reviewed in brief in a sequential manner. This paper gives a clear idea on the preliminary stage of wind energy followed by its gradual progress and perfection together with the latest innovation and research work carried by the scientists and engineers.

1.1. Before 18th Century

Coming to the 1st use of wind power, history goes back to 500 B.C. People used wind power to propel the boats in Nile opposite to river current [1]. The first known specific windmill, Pneumatics, was

[1] Research Assistant (PhD), Dept. of Electrical & Electronic, Faculty of Engineering, University of Nottingham, 43500 UNMC, Jalan Broga, Semenyih, Selangor, Malaysia, *Email: kecx1msa@nottingham.edu.my*

[2] Associate Professor, Dept. of Electrical & Electronic, Faculty of Engineering, University of Nottingham, 43500 UNMC, Jalan Broga, Semenyih Selangor, Malaysia, *Email: Rajprasad.Rajkumar@nottingham.edu.my*

[3] Senior Lecturer, School of Engineering, Taylor's University, Selangor, Malaysia, Taylor's, Selangor, Malaysia, *Email: aravindcv@ieee.org*

[4] Assistant Professor, Dept. of Electrical & Electronic, Faculty of Engineering, University of Nottingham, 43500 UNMC, Jalan Broga, Semenyih Selangor, Malaysia, *Email: YeeWan.Wong@nottingham.edu.my*

[5] Deputy General Manager (Geologist), Data Management Division, BAPEX (Bangladesh Petroleum Exploration & Production Company Limited), PetroBangla (Bangladesh Oil, Gas & Mineral Corporation), Ministry of Power, Energy and Mineral Resources, 4 Kawran Bazar C/A, Dhaka-1215, Bangladesh, *Email: Selima.shahnaz_geologist@yahoo.com*

[6] Research Assistant (PhD), Dept. of Electrical & Electronic, Faculty of Engineering, University of Nottingham, 43500 UNMC, Jalan Broga, Semenyih, Selangor, Malaysia, *Email: kecy2lys@nottingham.edu.my*

illustrated in the 1st century BC by Hero of Alexandria [2]. The purpose of creating it was to grind the corn. Although a figure (Figure 1) of the invention can be found, the existence of it has not well been established.

Vertical axis windmills were found in China in 13th century where as it was found long back in Persia around 900 AD. Along with the sailing concept, idea of wind turbine got developed gradually with the need of pumping water for irrigation; for example the ancient irrigation system of the island of Crete. This windmill (Figure 2) was used to rotate around its vertical axis. Nowadays, such a configuration is known as Savonius rotor. [3-4].

In European countries, the windmills first started to appear in the 12th century [3]. Although the design was changed, the primary purpose was still the same-grinding corn and pumping water. The turbines were used to be mounted on a house facing along with the wind direction. Those windmills were horizontal in nature. Starting from the year of 1700, the windmills found in Europe were improvised and developed with twisting blades (Figure 3) whereas a different configuration was developed in the United States (Figure 4). It was a multi-bladed windmill mostly recognized as fan mills [5]. It was given a nickname as 'Pumping Jack' as it was used mainly for pumping water. Over 6 million fan mills were built in the US before the starting of 19th century. Before the industrial revolution, windmills were one of the major energy sources [7].

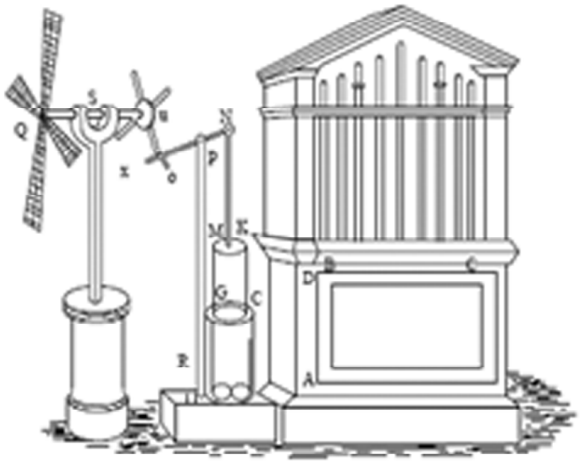

Figure 1: Pneumatics Windmill by Hero of Alexandria (1st Century BC)

Figure 2: Persian VAWT (900AD)

Figure 3: Dutch Windmill

Figure 4: American Pumping Jack

2. FROM THE YEAR BETWEEN 1800 TO 1900

In need of pumping water, followed by electricity, modern wind power technology was first explored. From 1850 onwards, windmills were being developed in large areas with a view to pumping waters [3]. The early farm windmills were made by woods which were extinct gradually except in the museum [3]. Figure 5 gave us an idea of those ancient historical windmills. The turbine picture was taken in Texas at J.B. Buchanan's firm.In 1880s, in order to develop medium sized wind plant with a view to achieving pumping and electricity demand on dairy industries, a Royal Commission was set up in Denmark. Later a company namely "Lykkegaard Company" brought the one kind of wind machine in the market in commercial basis. Those machines came with four blades. Later on, in the beginning of 20th century, hundreds of machines were manufactured [7].

In the year of 1888, a windmill was built to produce electricity by a person named Brush. That was the 1st automatic wind turbine that used to produce electricity [8]. It was constructed with a wooden rotor having a diameter of 17cm which was connected to DC generator via a gear box (step up) having a ratio of 50:1. In a strong wind situation, it used to produce 12kW. The problems of it were the giant size and the low rotational speed which was inefficient. It was operated nearly for 20 years [8]. In that time another wind turbine was built around in 1891 though it was experimental. It was built by PoulLaCour in Denmark which was driving a dynamo [9]. He conducted vast research on this field in 1890 and he made the baseline configuration of today's modern Horizontal Axis Wind Turbine [10].

From the year 1900 onwards, all of the windmills had multi blade system having an average of 3-5 m in diameter [7]. The prime time of farm windmills was the year between 1930s and 1940s in were they reached its pick [7]. In that period of time, no more wood was used rather than metal with multi-bladed vanes [7]. Around 6 million farms were in operation on that time to pump water for residential use together with water for livestock. Different countries such as Australia, Africa, Canada, United States, and Argentina were making use of them [7]. But due to in demand of less expensive machine, those farms started to exploit replaced by modern design wind turbines. In the beginning of the 20th century, a new idea came up in different countries. It was called Wind Chargers (Figure 6) [11]. It was quite popular in United States. Because of the high expense of transmission line and the huge distance to cover from isolated location to generating plant, some companies started constructing stand-alone wind system having a rotor of propeller type consisting of maximum 3blades. The generated electricity was stored in battery. Those batteries, called wet-cell, were made off with lead-acid and it used to require great maintenance care for longevity [8-11]. These machines differ a lot from the earlier windmills. Those windmills used to have multiple large number

Figure 5: Historical farm windmills at J. B. Buchanan farm. Location: Spearman Texas

Figure 6: Wind Charger (100 W, DC, with flap air brakes). Location: USDA-ARS wind test station, Bushland, Texas

of blades used to pump water of low volume. In capable of generating electricity because of slow rotational speed due to large number of blades, these wind chargers grew popularity but became outdated in 1940s and 1950s since electricity was made available in very cheap rate in United States from rural electric cooperatives [3].Starting from this time, wind turbines were thought of being used in utility. Therefore different types of designs and structure were brought into the market.

Focusing on different points of angles on how to deal with the wind energy, several shapes of blades were innovated with two kinds of turbine: one is horizontal axis wind turbine (axis of the rotor is horizontal) and another is vertical axis wind turbine (axis of the rotor is vertical) [3]. Though the concepts and partial implementation of both of them were brought up before, combined studies with advantages and disadvantages had been started. In 1926, a horizontal axis wind turbine having four blades was constructed by Flettner.It provided 30KW of rated power with a wind speed of 10 m/s. Meanwhile a guy named Madras came up with an idea of mounting vertical rotating cylinders on railroad cars. He proposed the Magnus Effect to drive the cylinder travelling around a circular track. The generator on the other hand was planned to be constructed on the axels of the car. The proposal turned into a prototype in 1933 but due to the inconclusive result, the idea was abandoned [3]. In the year of 1927, G. Darrieus built a rotor. His machine blades were similar to jumping rope. In 1931, he proposed a design using lift to produce torque around a vertical axis [11]. Darrieus patented the design of his rotor and it was known as Troposkien.

Meanwhile, Savonius discovered a rotor of S-shaped in Finland. It was built with two half of a cylinder and the distance between them was smaller than the diameter. This basically became the starting point of VAWTs [10-11]. Both of the machines of Savonius and Darrieus were designed with straight vertical blades and those two are called the main two types of modern vertical axis wind turbine [3]. Between 1940 and 1950, the two major achievements were made in terms of wind power history. The first revolution was the design of 3 blades wind turbine structure and the second was to introduce AC generator replacing DC [8]. The other one took place after the occurrence of revolution in USSR (Union of Soviet Socialist Republics), in Crimea, successful construction of 100KW wind machine prototype had been taken place between 1935 and 1953. It played importance for developing industrialization and agriculture. It was inter-connected in parallel with a conventional station. For the next 15 years further research had been carried through and around 30 prototypes with successful series production were achieved with a rated power of 30KW [7]. Meanwhile in USA, from 1939 to 1945, design and operation had been being taken place and finally at Vermont, engineers came up with the largest machine available that time. It had a diameter of 53m and the rated power was 1250KW. It gave a moderate performance for a brief period of time in a routing generation station [7]. The research and scope did not go further because of the World War II.

3. BETWEEN 1950 TO 1999

After the 2nd world war, the main research and analysis was focused in Europe. According to the DIWA which is Danish Wind Industry Association, the first modern wind turbine was built by engineer Johannes Juul in Denmark in 1956. It came with electromechanical yawing system. It was a three blades upwind turbine that used to have an asynchronous generator[3]. It had a rated power of 200KW and was called as “Gedser Wind Turbine” [6]. Built with a concept of horizontal axis, it was connected to a there phase AC power grid. Looking at the case history in United Kingdom, a national wind power committee was brought up in 1948 and continued till 1958. The committee worked with “Electrical Research Association” of United Kingdom. The main supervisor of the project was Lake E.W. A vast research regarding sites, building prototypes and wind survey had been carried through. One prototype had been installed at CostaHill by the supervision of John Brown Company in 1955 having a diameter of 15m and having a rated power of 1*00KW* witha wind speed of 16m/s. It was connected with a power grid which mainly ran in diesel. It was established in a remote side of Northern having high wind that blocked the development of mechanical features of it and ended up failing to be proven as reliable and ended up failing to be proven as reliable. The

Figure 7 (a): Darrieus concept

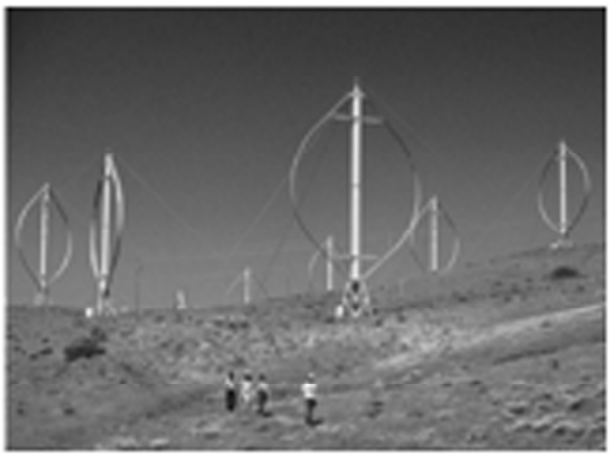

Figure 7 (b): FloWind turbine AT Tehachapi Pass

other one was located at St. Albans built by Enfield which was a low speed site. It was designed by Frenchman Adreau. It had a rated power of 100KW with a wind speed of 13m/s. The hollow blades and the rotation (while the blades were rotating, the air flowed through air turbine) made the turbine unique in nature [3]. Under British Electricity Authority (BEA), it failed to get permission for further innovation and was sent to Algeria where it was implemented successfully by a local company. However the system turned out to be inefficient and did not go further [7].

In this period of time, in 1970s, there was a great concern regarding the decrease of fossil fuel and limited resources which led to many researchers and surveys. The crisis of oil in the year between 1973 and 1979 also was added into the flow. As a result several wind power technologies were invented and the power capacity increased to 100KW and furthermore from 1980s, turbines with MW power was started to be designed [8]. It was also the time when European Countries first had the idea to put wind turbine into the see [6]. In that period of time, around in 1980, Danish industry came up with "Riisager Wind Turbine". Having almost the same concept as the Gester Wind Turbine, this one was built by used car parts which were very cheap and reasonable in price. It became very popular in numerous private households [12].

Coming back to VAWT again, in 1980s, Sandia National Laboratory (SNL) started a vast research with a 17 m high Darrieus's turbine [13]. FloWind purchased the design and implemented numerous amount of it in the United States (Figure7) and became the most successful VAWT manufacturer [2] [14]. Next, Dr. Peter Musgrove proposed H-type VAWT with straight blades which was known as H-type rotor. Mc Donnell took his concept and built a 40 kW H-rotor (Figure 8.1) [14]. Since, Darrieus patented his design, MC Donnell had to change the shape of the rotor and therefore he took the H-type motor concept to build a different shape of VAWT.

Fascinatingly in this period of time, VAWT concept began to spread in Europe. In Denmark, Riso invented their own H-rotor having a capacity of 15KW (Figure 8.2) [14]. In Canada, Eole had a 3.5 MW VAWT operated from 1987 to 1993. They had to shut it down as it was too costly in terms of bearings and maintenance [15]. Eole's was the biggest VAWT built in that period of time and also the last VAWT milestone of the early generation. After that, the research and study of VAWT stopped for a while but the development of HAWTs continued.

From the beginning of 1990s, wind energy has gained acknowledgement of one of the vital renewable sources. In the year of 1993, asynchronous generator in wind turbines was being started slowly changing to synchronous generator [16]. In the mid of 1990s, wind turbine was being started to build in offshore because of the strong wind in the high sea [17]. Although the technical difficulty and installation cost are higher in offshore, other conditions and cases stay in the favour of it comparing to onshore wind power energy.

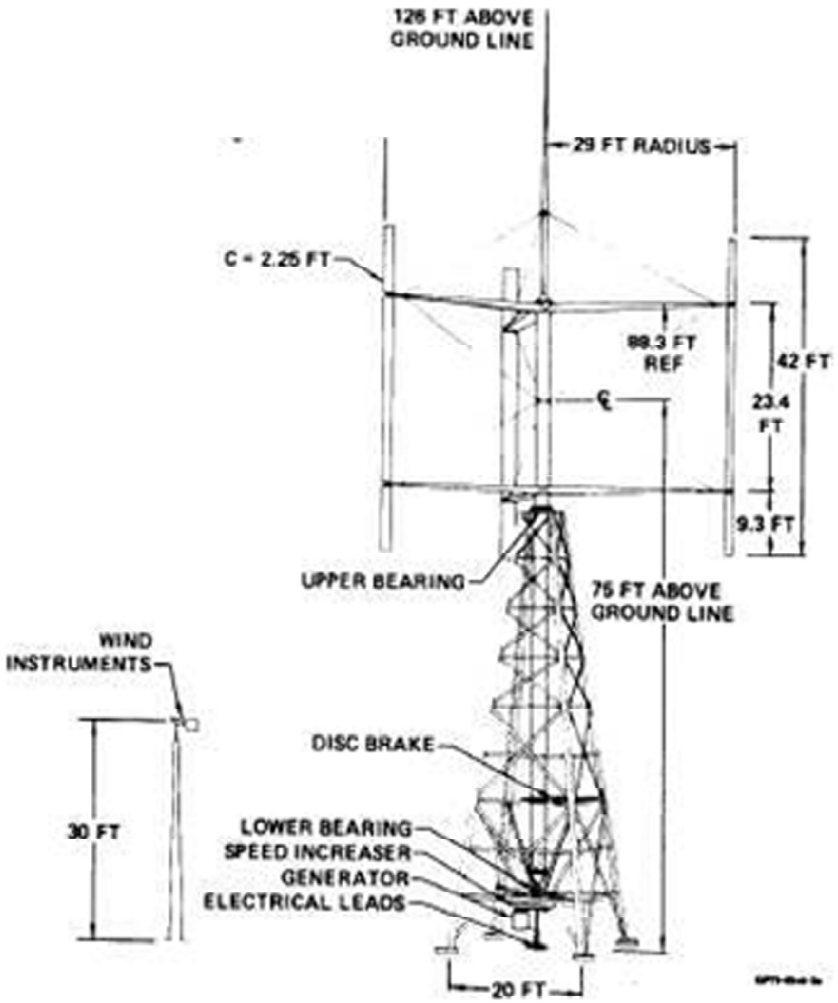

Figure 8 (a): MC Donnell's 40KW Design

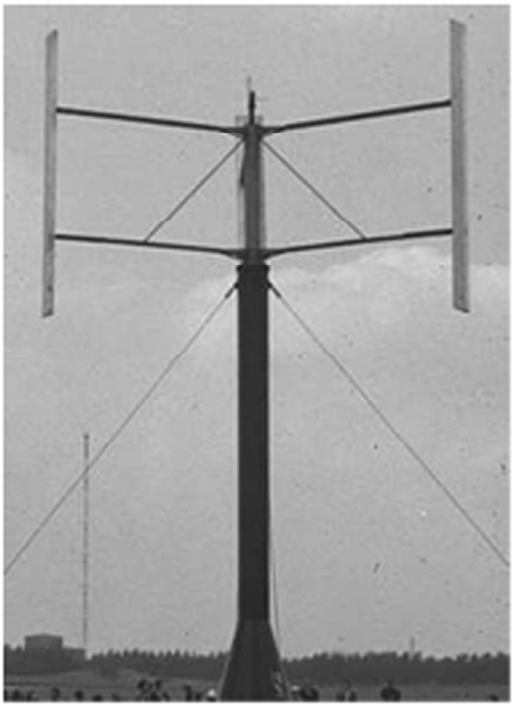

Figure 8 (b): Riso's 15KW Design

Firstly, wind speed is almost 25% greater than of onshore. Secondly, frame of tower is lower comparing to onshore; therefore it can face greater speed. Moreover the roughness is also less in sea level [6].

Although some European countries tried to develop a thought of spreading wind energy at sea level at 1970s, not much of progression took place that time except for couple of prototypes being tested [6]. The first country to build offshore wind turbine successfully in the middle of the sea was Denmark in the year of 1991. From 1991 to 1997, Denmark, Netherland and Sweden performed couple of prototype based wind turbine operations in deep sea [6]. Requiring less land area, less noise pollution, no greenhouse gas emission with an addition of great environmental protection, the offshore wind energy were getting popular among the European countries.By the end of 20th century, around 50 countries were running wind turbines generating approximately 17500 MW of electricity. More than 70% of this electricity was generated by the European countries. In 1999, Germany, Spain and Denmark being the leading countries produced an overall power of 7675MW which was almost 80% of the entire production of wind energy in Europe [18].

4. CONCLUSION: 21STCENTURY AND PRESENT SITUATION

Although there are a lot of activities going on towards the offshore wind energy, the development process was still very slow. But from the beginning of 21st century, the offshore deep blue wind technology has gained new inspiration. From the starting of 21st century, within 6 years of time, 21 offshore plants had been built in different countries namely Denmark, Sweden, Ireland, Germany and Netherlands [19]. By the end of 2006, installed capacity of offshore project in the entire world reached 798.2 MW [19]. Around time there were couple of famous projects which have to be mentioned-East China Bridge in Shanghai generating electricity of around 100MW, Shanghai FengxianNanhui Offshore Wind Power and Cixi Wind Power at sea in Zhejiang. European countries, America and other countries such as China also have been progressing firmly. China had constructed 59 wind farms by 2005 including 1883 turbine generator. They produced 1266 MW of Power in 2005 making sure to be one of the top 10 global wind energy producers [20]. The Northern side of the world has good wind energy but still development of wind power has not yet been observed that much due to couple of major problems until 2011. Among them, icing on the turbine blade is the main obstacle. In average 20% power loss occurred annually due to this problem. To overcome it, not much of steps were taken. In 2011, Muhammad S. Virk, Matthew C. Homola, Per J. Nicklasson from Narvik University College carried out a numerical study on a horizontal axis wind turbine (5MW) about the atmospheric ice accretion. The result was achieved using Computational Fluid Dynamics. For both of the conditions of rime and glaze ice, five different sections in the blades were taken into consideration for numerical analysis. Moreover, several atmospheric temperatures were used to simulate the rate and shape of accreted ice. The result indicated that both the blade size and relative section velocity of the blade affected ice growth. Near the root section, the icing was less. In the blade section, from centre to top, significant change in icing was noticed with the variation in atmospheric temperature. Furthermore, the result also proved that the icing could be managed by optimizing the geometric design parameters [21]. In recent years, Micro-Wind Energy has made a lot of impact due to its low speed operation along with low power applications resulting cost reduction and simplicity. For example, Massimiliano, Marcello and Gianpaolo from Italy designed a simple, effective and low cost Micro-Wind Energy Conversion System in 2011 that gathered several attentions. It used a Permanent Magnet Synchronous Generator, boost converted, and Voltage Oriented Controller were used. The system performed a reliable operation at the maximum power. It also showed a promising quick response with variable wind speeds. It had low losses and almost zero reactive power exchanged with the power grid.

In comparison with a conventional wind turbine of same maximum power range and with the same average wind speed, it could generate twice the energy produced by the generator [22]. With view of the facts stated above, it could easily be predicted that the renewable energy like wind power is taking over the fossil fuel gradually and we are looking towards the world where green energy dominate on large scale.

This paper provided the history of wind power in brief starting from the ancient timethat ends with modern era. At present, numerous projects on wind turbine are being implemented each day. This paper would certainly be a great source of information for those projects for further development.

REFERENCE

[1] S.M. Muyeen, Junji Tamura, T. Murata, Stability Augmentation of a Grid-connected Wind Farm, Springer-Verlag London Limited, 2009.

[2] A.L. Rogers J.F. Manwell, J.G. McGowan. Wind Energy Explained–Theory, Design and Application. John Wiley and Sons Ltd., second edition, 2009.

[3] V. Nelson, Wind Energy Renewable Energy and the Environment, Taylor and Fransis Group, LLC, United States of America, 2009.

[4] D. Zafirakis John K. Kaldellis. The wind energy revolution: A short review of a long history. Renewable Energy, 36: 1887–1901, 2011.

[5] Nick Jenkins Tony Burton, David Sharpe. Wind Energy-Handbook. John Wiley and Sons Ltd., first edition, 2001.

[6] L. Wang, J. Wei, X.W.X. Zhang, "The development and Prospect of Offshore Wind Power Technology in the World"

[7] D.F. Warne and P.G. Calnan, "Generation of Electricity from the Wind", IEEE Reviews, Vol. 124, No. 11r, November 2007, pp. 963-985.

[8] C. Wang, L.Wang, L. Shi and Y. Ni, "A survey on Wind Power Technologies in Power System," IEEE Conference, 2007.

[9] Jinsong Kang, Zhiwen Zhang and Yongqiang, "Development and Trend of Wind Power in China," in Canada Electrical Power Conference, 2007, pp. 330-335

[10] Nick Jenkins Tony Burton, David Sharpe. Wind Energy-Handbook. John Wiley and Sons Ltd., first edition, 2001.

[11] G.J.M. Darrieus. Turbine having its rotating shaft transverse to the flow of the current, 1931.

[12] L.H. Hansen, F. Blaabjerg, H.C. Christensen, U. Lindhard and K. Eskildsen, "Generators and Power Electronic Technology for Wind Turbine" The 27th Annual Conference of the IEEE Industrial Electronic Society, 2001, pp. 2000-2005

[13] James H. Strickland. The darrieus turbine: A performance prediction model using multiple steam tube model. Technical report, Sandia National Laboratories, 1975.

[14] Paul Gipe. Photos of vertical axis wind turbines by paulgipe. Website (31st January 2014), 2014. URL http://www.wind works.org/cms/index.php?id=219.

[15] Thomas D. Ashwill Herbert J. Sutherland, Dale E. Berg. A retrospective of vawt technology. Technical report, Sandia National Laboratories, 2012.

[16] L.H. Hansen, F. Blaabjerg, H.C. Christensen, U. Lindhard and K. Eskildsen, "Generators and Power Electronic Technology for Wind Turbine" The 27th Annual Conference of the IEEE Industrial Electronic Society, 2001, pp. 2000-2005

[17] I. Erlich and F. Shewarega, "Interaction of Large Wind Power Generation Plants with the Power System," First International Power and Energy Conference PECon, Putrajaya, Malaysia, November 28-29, 2006, pp. 12-18.

[18] Nikos Hatziargyriou and ArthurosZervos, "Wind Power Development in Europe," IEEE, Vol. 89, No. 12, December 2001 pp. 1765

[19] Zaharim, S. K. Najid, A. M. Razali and K. Sopian "Wind Speed Analysis in the East Coast of Malaysia," European Journal of Scientific Research, Vol. 32, No. 2, 2009, pp. 208-215.

[20] Jinsong Kang, Zhiwen Zhang and Yongqiang, "Development and Trend of Wind Power in China," in Canada Electrical Power Conference, 2007, pp. 330-335

[21] M. S. Virk, Matthew C. Homola, Per J. Nicklasson, "Atmospheric icing on large wind turbine blades," International Journal of Energy and Environment, Vol. 3, Issue 1, 2012, pp. 1-8.

[22] Li Yan, Chi Yuan, Han Yongjun, Li Shengmao and Tagawa Kotaro, "Numerical simulation of icing on static flow field around blade airfoil for vertical axis wind turbine," International Journal of Agric. & Biol. Eng. Vol. 4, No. 3, September 2011, pp. 41-47.