PERFORMANCE PREDICTION IN HAWT WIND POWER TURBINE

Navin Kumar Kohli* and Eshan Ahuja
* Research Scholar, JJT University, India
Email: navinkkohli@gmail.com

ABSTRACT

Energy is our life and plays an important role in India’s socio-economic development and growth. Renewable energy sources like wind energy is pure, green, and indigenous and can help in reducing the dependency on fossil fuels. Wind is the indirect form of solar energy and is always being replenished by the sun. Wind is caused by differential heating of the earth’s surface by the sun. It has been estimated that roughly 10 million MW of energy are continuously available in the earth’s wind. Wind energy provides a variable and environmental friendly option and national energy security at a time when decreasing global reserves of fossil fuels threatens the long-term sustainability of global economy. The Horizontal Axis Wind Turbine (HAWT) is the most efficient design for turning wind into electricity. The basic design allows two or more rotor blades to face into the wind. Most HAWT are installed on towers to help them reach high above the ground where airflow is strongest and most constant. The wind turbine aerodynamics of a horizontal-axis wind turbine is not straightforward. The air flow at the blades is not the same as the airflow further away from the turbine. The very nature of the way in which energy is extracted from the air also causes air to be deflected by the turbine. In addition the aerodynamics performance of a wind turbine at the rotor surface exhibit phenomena that are rarely seen in other aerodynamic fields.

This paper studies the sustainability of renewable energy technology with special reference to performance of horizontal axis wind turbine. The different existing performance and reliability with various problems related to wind turbine components for wind energy system have been discussed. This paper also discusses different techniques for enhancement of performance of HAWT wind energy system.

Keywords: Wind power technology; HAWT, Reliability evaluation model; Aerodynamic model; Wind resource assessment

INTRODUCTION

Electricity is a fundamental asset without which modern society simply could not exit. Electricity provides us with heat, light and hot water etc and it runs all kinds of tools and domestic appliances that we have come to rely on in our everyday lives. Electricity is vital
to our high-speed world, and there is a growing global demand for energy but also for reduced strain on the environment.

On this road, wind turbine technology has a unique technical identity and unique demands in terms of the methods used for design. Remarkable advances in the wind power design have been achieved due to modern technological developments. Since 1980, advances in aerodynamics, and structural dynamics have contributed to a 5% annual increase in the energy yield of the turbines. Current research techniques are producing stronger, lighter and more efficient blades for the turbines. The annual energy output for turbine has increased enormously and the weights of the turbine and the noise they emit have been halved over the last few years. We can generate more power from wind energy by establishment of more number of wind monitoring stations, selection of wind farm site with suitable wind electric generator, improved maintenance procedure of wind turbine to increase the machine availability, use of high capacity machine, low wind regime turbine, higher tower height, wider swept area of the rotor blade, better aerodynamic and structural design, faster computer-based machining technique, increasing power factor and better policies from Government.

Even among other applications of renewable energy technologies, power generation through wind has an edge because of its technological maturity, good infrastructure and relative cost competitiveness. Wind energy is expected to play an increasingly important role in the future national energy scene. Wind turbines convert the kinetic energy of the wind to electrical energy by rotating the blades.

Greenpeace states that about 10% electricity can be supplied by the wind by the year 2020. At good windy sites, it is already competitive with that of traditional fossil fuel generation technologies. With this improved technology and superior economics, experts predict wind power would capture 5% of the world energy market by the year 2020. Advanced wind turbine must be more efficient, more robust and less costly than current turbines. Ministry of Non-conventional Energy Sources (MNES), Indian Renewable Energy Development Agency (IREDA) and the wind industry are working together to accomplish these improvements through various research and development programs. This article gives a brief overview of wind turbine technologies.

Global wind power markets have been for the past several years dominated by three major markets: Europe, North America (US), and Asia (China and India). While these three markets still accounted for 86% of total installed capacity at the end of 2009, there are signs that this may be changing. Emerging markets in Latin America, Asia and Africa are reaching critical mass and we may be surprised to see one or more of them rise to challenge the three main markets in the coming years.

Commercial wind farms now operate in close to 80 countries, and present many benefits for both developed and developing countries: increased energy security; stable power prices; economic development which both attracts investment and creates jobs; reduced dependence on imported fuels; improved air quality; and, of course, CO2 emissions reductions. Each of these factors is a driver in different measure in different locations, but in an increasing number of countries they combine to make wind power the generation technology of choice. What role will wind power play in the coming two decades and beyond? How much of the global electricity demand will it cover? How much CO2 will be saved by wind power in 2020 and in 2030? And what will it do for energy independence and economic growth? These are the questions that the GWEO seeks to answer. We present three scenarios for the development of the sector here, and play them
off against two scenarios for electricity demand development to come up with a range of possible futures for the sector. Our answers to these questions haven’t changed dramatically since the 2008 edition, although the performance of the industry in the last two years tracked ahead of our Advanced scenario. What has changed is the IEA’s Reference Scenario. In 2006, the Reference scenario projected 231 GW for 2020 – now that’s up to 415 GW; and for 2030, the Reference scenario projected 415 GW now that’s up to 573GW. Of course, we still think those numbers are very low, but we were very pleased to see that the 2010 edition of the IEA’s publication Projected Costs of Generating Electricity has onshore wind power replacing oil to join coal, gas and nuclear as the main technologies which will compete for market share in the power sector of the future.

India’s rapidly growing economy and expanding population make it hungry for electric power. In spite of major capacity additions over recent decades, power supply struggles to keep up with demand. Electricity shortages are common, and a significant part of the population has no access to electricity at all. India’s electricity demand is projected to more than triple between 2005 and 2030. The IEA predicts that by 2020, 327 GW of power generation capacity will be needed, which would imply the addition of 16 GW per year.

This urgent need is reflected in the target the Indian government has set in its 11th Five Year Plan (2007-2012), which envisages an addition of 78.7 GW in this period, 50.5 GW of which is coal, and 10.5 GW new wind generation capacity, plus 3.5 GW other renewables. The Indian Ministry of New and Renewable Energy (MNRE) estimates that there is a potential of around 90 GW for power generation from different renewable energy sources in the country, including 48.5 GW of wind power, 14.3 GW of small hydro power and 26.4 GW of biomass.

The current figures are based on measurements from only nine states, and which were taken at low hub heights, in line with old technology. A more recent wind atlas published by the Center for Wind Technology (CWET) in April 2010 estimated the resource potential at 49,130 MW. This was based on an assumed land availability of 2% and 9 MW of installable wind power capacity per square kilometer. It seems likely that the wind power potential is considerably underestimated. The Indian Wind Turbine Manufacturers Association (IWTMA) estimates that at hub heights of 55–65 meters, potential for wind development in India is around 65–70 GW. The World Institute for Sustainable Energy, India (WISE) considers that with larger turbines, greater land availability and expanded resource exploration, the potential could be as great as 100 GW.1

At the end of 2009, India had 10,926 MW of installed wind capacity, and 11,807 MW were reached by the end of the country’s financial year on 31 March 2010. However, wind power in India is concentrated in a few regions, especially the southern state of Tamil Nadu, which maintains its position as the state with the largest wind power installation.

It had 4.6 GW installed on 31 March 2010, representing close to 40% of India’s total wind capacity. This is beginning to change as other states, including Maharashtra, Gujarat, Rajasthan, Karnataka, West Bengal, Madhya Pradesh and Andhra Pradesh start to catch up, partly driven by new policy measures.

India ratified the Kyoto Protocol in August 2002, and the possibility to register projects under the Clean Development Mechanism (CDM) provided a further incentive to wind energy development. By 1 September 2010, 416 Indian wind projects were in the CDM pipeline, accounting for 6,839 MW, second only to China. India’s wind energy potential has only been partially realized due to the lack of a coherent national renewable energy
policy. Currently, the promotion of renewable energy in India is mainly driven by state governments. While some states have set high renewable portfolio standards, other states only have low or no targets, and enforcement is insufficient.

Furthermore, while in theory, RPS and feed-in-tariffs can coexist, this needs to be well managed to avoid inefficiencies. The lack of a national policy is hampering genuine progress. Until very recently, the promotion of renewable power generation at a national level relied on one clause of the 2003 Electricity Act. This act restructured the Indian electricity industry by unbundling the vertically integrated electricity supply utilities in the Indian States and establishing State Electricity Regulatory Commissions (SERCs) in charge of setting electricity tariffs. It also required the SERCs to set Renewable Portfolio Standards for electricity production in their state, and the Ministry for New and Renewable Energy (MNRE) issued guidelines to all state governments to create an attractive environment for the export, purchase, wheeling and banking of electricity generated by wind power projects. Some of the government’s broad national policy guidelines include fiscal and financial incentives, wheeling, banking and third party sales, buy-back facility by states, land policies favouring wind farm development, financial assistance, and wind resource assessment.

In December 2009, India’s Ministry of New and Renewable Energy (MNRE) announced a national generation-based incentive (GBI) scheme for grid connected wind power projects, for the cumulative capacity of 4,000 MW to be commissioned by March 2012. The GBI scheme provides an incentive of 0.5 Rupees per KWh (0.8 Euro cents) in addition to the existing state feed-in tariff. Investors who because of their small size or lack of tax liability cannot benefit from accelerated depreciation under the Income Tax Act can opt for this alternative incentive instead, up to 31 March 2012 or before the introduction of a new Direct Tax Code, whichever is earlier. After this date, the Accelerated Depreciation may be phased out. This should facilitate the entry of large Independent Power Producers (IPPs) into the wind market, attract foreign direct investment and level the playing field between different types of investors. In addition, since this incentive is based on actual electricity production, rather than installation, it stimulates higher efficiencies. India has a solid domestic manufacturing base, with current production capacity of 4,500-5,000 MW/year. Wind turbine manufacturers operating in India include Indian company Suzlon, which is now a global leader. 17 companies now manufacture wind turbines in India and another eight are in the process of entering the Indian wind power market, through either joint venture under licensed production, as subsidiaries of foreign companies or as Indian companies with their own technology. It is expected that the annual production capacity will rise to 10,000+ MW by 2012-2013, according to WISE. Some of these foreign companies now source more than 80% of the components for their Indian-manufactured turbines from India. Wind turbines and turbine blades have been exported from India to the USA, Europe, Australia, China and Brazil.

However, for India to reach its potential and to boost the necessary investment in renewable energy, it will be essential to introduce clear, stable and long-term support policies, carefully designed to ensure that they operate in harmony with existing state level mechanisms and do not reduce their effectiveness.
PERFORMANCE AND RELIABILITY OF HAWT WIND TURBINES

The Horizontal Axis Wind Turbine (HAWT) is the most efficient design for turning wind into electricity. The basic design allows two or more rotor blades to face into the wind. Since they are all being simultaneously moved, they form the least possible resistance to wind forces.

The rotor blades of a Horizontal Axis Wind Turbine usually have an aerodynamic design. On a wing or rotor blade, the top side of the blade has a longer surface area than the bottom. When the air moves over the top of the blade, the air must move faster than the air going under the bottom of the blade. This higher speed creates lift because the denser underside air pushes against the blade. The blades are hooked to a shaft so the lift on the blade forces the shaft to spin.

Researchers and scientists had developed various models for the evaluation of performance of wind turbine system. A brief review of these models has been presented here. Abderrazzag had investigated the performance and energy production of a grid connected wind farm during 6 years operation and illustrated the variation in energy and wind speed on an annual and monthly basis for the whole examined period [21]. Saramourtsis et al. presented a probabilistic method used for the evaluation of the performance and reliability of wind-diesel energy systems [22]. Castro Sayas and Allan built a probabilistic model of a wind frame taking into account the stochastic nature of the wind, the failure and repair processes of wind turbines, and the spatial wind-speed correlation and wake effects [23]. Dokopoulos et al. proposed a Monte Carlo-based method for predicting the economic performance and reliability of autonomous energy systems consisting of diesel generators and wind energy converters (WECs) [24]. Abouzahr and Ramkumar studied the performance of an autonomous WECS composed of one wind turbine feeding the load via battery storage [25].

Billinton and Guung bai conducted studies on generating capacity adequacy associated with wind energy, using a sequential Monte-Carlo simulation procedure. The result shows that the contribution of WECs to the reliability performance of a generating system is highly dependent on the site wind condition [26]. A sequential Monte-Carlo simulation technique based on an hourly random simulation had been proposed by Billinton et al. for adequacy evaluation of a generating system including WECS [27]. Bhatt et al. studied prediction and enhancement of performance of wind farm in India and found that there is scope for improvement in the annual plant load factor by 1–3% by improving the grid and machine availability [28].

A detailed parametric analysis such as available wind potential quality, examination of wind power curve, investigation of reliability for determining minimum cost is carried out concerning the optimum sizing of stand-alone wind power system by Kaldellis resulted in an appropriate decision making procedure, a significant reduction of the system dimensions may be realized leading to a remarkably diminished first installation cost [29]. Kelouwani et al. studied nonlinear identification of wind turbine with a neural network, and found that variable speed wind turbine can produce 8–15% more energy output as compared to their constant speed counter parts [30]. Wilson studied the various losses such as aerodynamic, mechanical, electrical, transmission and generator losses that reduce the power output. In that transmission and generator losses are of the order of 12% at rated power. The rotor performance is depending on the action of lift and drag forces on the blades [31].
HAWT RELIABILITY

Reliability of wind turbine system is based on the performance of its components under assigned environment, manufacturing process, handling, and the stress and aging process. Bakirtz developed a probabilistic technique to evaluate the reliability of an autonomous system [32]. Singh and Lago-Gonzalez used chronological simulation to model nondispatchable sources at each hour as multistate units, which are then convoluted with the conventional generation system model to evaluate the reliability coefficients [33].

Milborrow had analyzed operating cost, availability and reliability of new and old machines in Germany [34]. Chands et al. had studied the expert-based maintenance methodology. It has the potential to improve the reliability of systems, besides the conventional monitoring function [35]. Denson analyzed the failure causes for electronic systems and factors contributing to failure cause parts [36]. The development of a structural safety assessment program with emphasis on wind effects had been described by Chen et al. and the traditional reliability index had been used in his studies and presented difficulties in the development of a program for estimating component probability of failure values [37].

WIND TURBINE TECHNOLOGY

Bhutt et al. reviewed the development of the technology of wind turbines and the various parameters related to the wind energy conversions [38]. Karaki et al. described the development of a general probabilistic model of an autonomous wind energy conversion system composed of several wind turbines connected to load and battery storage and to evaluate the energy purchased from or injected to the grid in the case of grid-connected systems [39]. Shikha et al. reviewed the research and development of technology of wind turbines and its impact on the cost of wind energy systems. Also the gap between the theoretical research and practical implementation had been analyzed and the problems associated with this have been outlined [40]. The cost and features of smaller machines had been compared by Parthan et al. with multi MW class wind turbine over 2MW and there is a possibility of second-hand equipment in the 200–1000kW range may be retrofitted with large unit size machines [41]. Eize de Vries considered the latest developments in wind turbine technology and looks at turbines that have come onto the market in recent months. He also reported on the state of the industry and future challenges that manufacturers will have to face [42].

PERFORMANCE OF HAWT

There are several aspects of the methods currently used for the design calculation of wind turbine performance and loading. The different types of analysis and methods for the design of wind turbine systems have been reviewed in this literature in a detailed manner. According to Thomas and Urquhart, at present, both the horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT) designs are very efficient, however both are being rigorously tested and improved [44]. Solero et al. had presented the design and testing of 5 kW direct-drive wind generator pilot plant being developed for stand-alone systems installed in extremely cold climates [45]. In professional practice throughout the world, design wind loads for a vast majority of structures have been
evaluated by Singh on the basis of wind load provisions specified in standards and codes [46]. Chedid and Rahman performed a deterministic analysis to obtain optimal design for hybrid wind-solar power systems [47].

Ernesto et al. had developed a multi-objective optimization method for the design of HAWTs, based on the coupling of an aerodynamic model implementing the blade element theory and evolutionary algorithm. Somasekhar et al. presented a methodology for the system design, selection of wind farm site and wind electric generator based on technical and economical analysis [48]. Quarton suggested the approach to wind turbine design has been transformed to the point where sophisticated computer-based analysis is now performed routinely throughout the industry. The increased power and memory of computers, coupled with the possibilities for extremely user-friendly software environments, allowed the wind turbine designer to undertake sophisticated design calculations in a straightforward and convenient manner [49]. Tempel et al. had described the large mass design of wind turbines would drive up cost. But by reducing the mass the cost effective turbine can be designed. To design a cost effective flexible system thorough understanding of the dynamics is essential [50].

As part of the design process, a wind turbine must be analyzed for aerodynamic loads, gravitational loads, inertia loads and operational loads it will experience during its design life. Researchers had developed various mathematical models for the calculation of structural loads and material stresses. A brief review of these mathematical models has been presented here.

Manuel et al. continued the work of Veers and Winterstein using probabilistic methods and parametric models based on uncertainty analysis was also performed. The effect of varying turbulence levels on long-term loads extrapolation techniques was examined using a joint probability density function of both mean wind speed and turbulence level for loads calculations. Fitzwater and Winterstein examined the effect of statistical uncertainty dependent on the type of data used in these extrapolation methods. Bierbooms had applied a probabilistic method to determine the extreme response of pitch regulated wind turbine caused by wind speed gusts. The proposed more accurate description of extreme loading will enable wind turbine manufacturers to build more reliable and optimized wind turbine. Cluster analysis technique was used by Gomez-Munoz and Porta-Gandara during 2002 to find the local wind patterns for modeling renewable energy systems, which strongly depends on wind load [51].

A follow-up study by Ronold and Larsen, as well as Madsen et al. showed that these techniques could be used for ultimate load extrapolation and discovered that the statistics of the extremes more closely followed Gumbel-based distributions, as opposed to Weibull models commonly used for fatigue loading. Mejia et al. described a positive regulator for the angular velocity of small wind turbines. This regulator reduced gyroscopic loads was easy to adjust and could be manufactured in smaller sizes and was much stronger than conventional vane used in small wind machine. Veers and Winterstein studied the use of moments for predicting long-term fatigue loading and also introduced a nonlinear parametric model which was useful for extrapolating from limited data sets. Ronold et al. had published a complete analysis of the uncertainty in a wind turbine blade fatigue life calculation. They used a parametric definition of the fatigue loads, matching the first three moments of the wind turbine cycle loading distribution to a quadratic (transformed by a squaring operation) Weibull distribution and also studied calibration of partial safety factors. Veers et al. had presented a methodology for using measured or simulated loads to produce a long-term fatigue-load spectrum at specified environmental conditions and at desired confidence levels. Cheng et al. had considered extreme gust during the design process of the wind turbine with a rated power of 3MW and used different distribution
types, namely Rayleigh, Weibull and Gumbel distributions to provide a rational approach to determine the extreme gust response [52]. Verheij had developed a Gust Model for the design of large wind turbines and he explained the various wind loads and it causes. It investigated the influence of turbulence conditions on the design loads for wind turbine using inverse reliability technique and suggested that the inverse first-order reliability method in an efficient and accurate technique of predicting extreme loads and found that the higher relative turbulence at the onshore site leads to larger blade bending design loads than at the offshore site. Dahlberg et al. It described the results and conclusions drawn from measurements of structural loads in a wind turbine operating in a windfarm. The study showed that operation in a wake gives an increase in blade load variation. LeRoy et al. had presented a methodology for proceeding from the short-term observation of extremes to the long-run load distribution of these extreme events, for both flap and edge loading in both operating and parked with turbine conditions [53]. Stol and Mark calculated aerodynamic loads by aerodynamic subroutines at prescribed elements along each blade length, using blade-element theory [54].

BLADE AEROFOIL FOR HAWT

The development of special purpose aerofoil for HAWT began in 1984. New aerofoils have been developed to meet the specific demands of wind turbine. This has resulted in a greater efficiency of energy capture. Many researchers had developed different techniques for design, testing, fatigue strength analysis of wind turbine blades have been reviewed in the following literature. Padgett had developed a multiplicative damage model for strength of fibrous composite materials. This new model is needed to describe the failure of strength of these materials [55]. A simple micro-mechanical modeling procedure for evaluating fatigue strength unidirectional fibers composite had been described by Huang. It was expected that the present modeling approach is applicable to the fatigue analysis of laminated composites including in-phase and out of phase thermal-mechanical fatigue problems [56]. Fuglsang et al. had presented design and verification of the RISO-131 aerofoil family for wind turbines. High design lift coefficient of airfoils allowed the design of slender blades of wind turbine. Slender blades reduced both fatigue and extreme loads. Dutta et al. studied the early airfoils, which were based on readily available aviation data and exhibited low lift-to-drag ratio with moderate power coefficient of the rotor. Modern blade evolved to its present shape through specific development effort, has achieved higher lift-to-drag ratio and increased power coefficient of about 0.5, and increase by about 20% [57].

A computerized method has been developed by Bir to aid preliminary design of composite wind turbine blades. The method allows for arbitrary specification of the chord, twist, and aerofoil geometry along the blade and an arbitrary number of shear webs [58]. Migliore et al. had conducted aeroacoustic tests of seven aerofoils in wind tunnel. The test revealed that the trailing edge noise was dominant in clean tunnel flow and the leading edge noise was dominant in turbulent flow for all airfoils.

CONCLUSION

Recently in the energy scenario, there has been an increase in the demand for the utilization of clean renewable energy sources. This is a direct result of a rise in oil/coal prices and an increased awareness of human induced climate change through out the world. Wind energy has been shown to be one of the most promising sources of renewable energy. With current technology, the low cost of wind energy is competitive with more conventional sources of energy such as coal. There is number of way to explore the
possibility increasing the performance and optimizing wind turbine blade design for low wind speed areas. One issue with blades designed for low wind speeds is that they experience high stresses high wind speeds found in the occasional storm for example. It has been hypothesized that a swept tip will help relieve the stress found at the hub/blade interface with a span twist. For further study, there is continuous scope for performance enhancement for HAWT wind turbine.

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