Potential application of nanotechnology in wind turbine blades

Literature Review: Potential Application of Nanotechnology in Wind Turbine Blades

Introduction

Wind energy is growing rapidly as a renewable energy source worldwide. In 2017 a capacity of 52, 492MW of new wind turbines were installed, more than double that of 10 years ago [1]. A major trend in offshore wind turbine development is the increase in the size of the blade diameter because the extracted wind power is directly proportional to the surface area of the blade [2]. Increasing the size of the wind turbine blade (WTB) means the weight increases and the blades will deflect more, so the structural stiffness of the blade is of increasing importance. The demand for developing stronger and lighter WTBs has caused an increase in research for using nanotechnology using carbon nanotubes (CNTs), nanosilica and graphene as a reinforced hybrid composite to replace fibre reinforced polymers (FRP) currently used [3-5].

Discussion

Off-shore WTBs are exposed to extreme weather conditions and have to deal with high dynamic loads, rapid changes in wind direction, extreme wind gusts, wake effects from neighbouring wind turbines and lightning strikes [6]. In Japan, the average number of faults caused by lightning strikes per 100 turbine years can reach as high as 36 [7]. CNTs have the advantage of being high electrical conductors to divert the lightning current, they have high thermal conductivity to dissipate heat generated from lightning strikes and they also have excellent chemical and thermal stability to withstand heat arising [4]. General Electric is developing a hydrophobic nanocoating to prevent ice formation on WTBs [5]. Ice can disrupt the aerodynamics of the blade and reducing its efficiency as well as unbalancing the load distribution potentially causing structural fatigue reducing its lifetime. In extreme cases, it could stop the operation of the wind turbine [6].

Several studies have been carried out to review the mechanical properties of CNTs in the form of a polymer nanocomposite [7-9], and a general conclusion is that CNTs can improve the strength, the elastic modulus and the fracture toughness by 20%, 24% and 60%, respectively [11]. It has also been found to reduce the propagation of interlaminar cracks which can be a problem in traditional FRPs [4]. Experimental studies have demonstrated that epoxy composites containing a small number of CNTs can increase the lifespan of the blade up to 1500% [6]. A report by Laura Merugula found that a weight saving of up to 20% potentially resulting in an increased lifetime of the blades in 2MW and 5MW turbines with the addition of 1-5 wt% of CNTs [12]. Numerical studies have also demonstrated that the advances in the blade’s lifetime compared with the current composites justifies the additional investment required to produce WTBs from nano-reinforced composites [3]. There are however studies that illustrate the practical and economic issues that currently prevent nanocomposite WTBs being widely adopted [13].

To ensure wind turbines are appropriately engineered against damage from hazards within the planned lifetime they must conform to the international standard IEC 61400 published by the International Electrotechnical Commission (IEC). The standard isn’t specific to the types of materials that but be used to make WTBs, but full-scale prototype blades are to be tested both statically and dynamically to meet set criteria under the requirements of IEC 61400-23.

Conclusion

The application of nanotechnology in wind turbine blades is still in the research and development stage but it can be said that they offer many advantages over the current fibre reinforced polymers used to date. They allow for a reduction in blade weight, increased reliability, longer operational life and improved efficiency/cost in the near future.

The main factors under consideration are manufacturing cost, environmental factors, site-specific etc. Wind energy competes with other conventional sources for market share [13].

The weight of wind turbine also creates a problem in transportation and installation of the wind turbine. The increase in weight of wind turbine leads to increase in weight and cost of towers which will increase the installation cost.

full-scale level prototypes of the blade are tested both dynamically and statically following the requirements in the IEC 61400-23 standard on full-scale testing

IEC 61400-23: 2014 Full-scale structural testing of rotor blades

The 61400 is a set of design requirements made to ensure that wind turbines are appropriately engineered against damage from hazards within the planned lifetime. The standard concerns most aspects of the turbine life from site conditions before construction, to turbine components being tested, [1] assembled and operated.

At full-scale level prototypes of the blade are tested both dynamically and statically following the requirements in the IEC 61400-23 standard on full-scale testing. Full-scale blade tests are performed on typically one or two blades in order to verify that the blade type has the load carrying capability and service life provided for in the design. Since the cost of a blade itself is high, the blade is large and usually equipped with a lot of transducers, sensors and instruments, and the time needed for the dynamic test and the subsequent data analysis can be several months for large blades, the cost due to waiting time for market introduction is also significant.

References

1. GWEC, ‘ Statistics – GWEC’, *Statistics* . [Online]. Available: https://gwec. net/policy-research/statistics/. [Accessed: 27-Dec-2018].
2. S. Boncel, A. Kolanowska, A. W. Kuziel, and I. Krzyżewska, ‘ Carbon Nanotube Wind Turbine Blades: How Far Are We Today from Laboratory Tests to Industrial Implementation?’, *ACS Appl. Nano Mater.* , Nov. 2018.
3. G. Dai and L. Mishnaevsky Jr., ‘ Carbon nanotube reinforced hybrid composites: Computational modeling of environmental fatigue and usability for wind blades’, *Compos. Part B Eng.* , vol. 78, pp. 349–360, Sep. 2015.

4. P.-C. Ma and Y. Zhang, ‘ Perspectives of carbon nanotubes/polymer nanocomposites for wind blade materials’, *Renew. Sustain. Energy Rev.* , vol. 30, pp. 651–660, Feb. 2014.
5. A. Garland, ‘ Wind Turbines’, *Nanotech Magazine* , pp. 4–5, 05-Sep-2014.
6. L. Mishnaevsky, K. Branner, H. N. Petersen, J. Beauson, M. McGugan, and B. F. Sørensen, ‘ Materials for Wind Turbine Blades: An Overview’, *Materials* , vol. 10, no. 11, p. 1285, Nov. 2017.
7. F. Rachidi, M. Rubinstein, and A. Smorgonskiy, ‘ Lightning Protection of Large Wind-Turbine Blades’, in *Wind Energy Conversion Systems: Technology and Trends* , S. M. Muyeen, Ed. London: Springer London, 2012, pp. 227–241.
8. E. T. Thostenson, Z. Ren, and T.-W. Chou, ‘ Advances in the science and technology of carbon nanotubes and their composites: a review’, *Compos. Sci. Technol.* , vol. 61, no. 13, pp. 1899–1912, Oct. 2001.
9. P.-C. Ma, N. A. Siddiqui, G. Marom, and J.-K. Kim, ‘ Dispersion and functionalization of carbon nanotubes for polymer-based nanocomposites: A review’, *Compos. Part Appl. Sci. Manuf.* , vol. 41, no. 10, pp. 1345–1367, Oct. 2010.
10. R. F. Gibson, E. O. Ayorinde, and Y.-F. Wen, ‘ Vibrations of carbon nanotubes and their composites: A review’, *Compos. Sci. Technol.* , vol. 67, no. 1, pp. 1–28, Jan. 2007.
11. Y. Geng, M. Y. Liu, J. Li, X. M. Shi, and J. K. Kim, ‘ Effects of surfactant treatment on mechanical and electrical properties of CNT/epoxy nanocomposites’, *Compos. Part Appl. Sci. Manuf.* , vol. 39, no. 12, pp. 1876–1883, Dec. 2008.

12. L. A. Merugula, V. Khanna, and B. R. Bakshi, ‘ Comparative life cycle assessment: Reinforcing wind turbine blades with carbon nanofibers’, in *Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology* , 2010, pp. 1–6.

13. M. R. Loos and K. Schulte, ‘ Is It Worth the Effort to Reinforce Polymers With Carbon Nanotubes?’, *Macromol. Theory Simul.* , vol. 20, no. 5, pp. 350–362, Jun. 2011.