Journal of Thermal Engineering
Yildiz Technical University Press, Istanbul, Turkey
Vol. 2, No. 1, pp. 557-565, January 2016.

http://eds.yildiz.edu.tr/journal-of-thermal-engineering/Articles
Manuscript Received June 27, 2014; Accepted August 22, 2014

This paper was recommended for publication in revised form by Editor in Chief Ahmet Selim Dalkilic

SIMULATION OF WIND TURBINES UTILISING SMART BLADES

***Alireza Maheri**
Northumbria University
Newcastle upon Tyne, UK

Keywords: wind turbine, smart blade, adaptive blade, morphing blade, microtab, trailing edge flap, telescopic blade
** Corresponding author: Alireza Maheri, Phone: +44 (0) 191 227 3860*
E-mail address: Alireza.Maheri@northumbria.ac.uk

ABSTRACT

Wind turbine smart blades change their aerodynamic characteristics in response to changes in operating condition, aiming at enhancing the power capture capability or controlling the power and aerodynamic load. Smart blades span a wide range of technologies. Some of these technologies have been proposed and developed specially for wind turbines, while some others have been borrowed from aircraft applications. Adaptive blades, telescopic blades, morphing blades, blades equipped with active control surfaces are some examples of smart blades. This paper presents a summary of wind turbine smart blades and advances in simulation and design of these blades.

INTRODUCTION

Wind turbines are designed to produce maximum power at the most probable wind speed. At high wind speeds, the generated power by a wind turbine far exceeds the generator capacity. To protect wind turbine operation at high wind speeds it is needed to limit the generated power otherwise it overloads the generator. While power control is an essential control for all wind turbines, aerodynamic load control is the main challenge for large wind turbines. As the size of wind turbine increases, larger blades and larger aerodynamic loads demand for either new blade materials or fast-response load alleviation mechanisms in place.

Pitch control and stall regulation are the most popular power control systems both based on controlling the flow angle of attack. Stall regulation is mechanically the simplest controlling strategy. In stall regulated wind turbines the blades have been designed to stall in high winds without any other control. The rotor is built with the blades fixed on the hub therefore it is rather simple in construction and the pitch of the blades are adjusted only once when the wind turbine is erected. In order to achieve stall-regulation at appropriate wind speeds, the wind turbine blades operate closer to stall and result in lower aerodynamic efficiency below rated power. Stall regulated wind turbines normally do not have a perfectly flat power curve above the rated wind speed.

While stall regulation is the simplest power control mechanism, pitch control is the most common means of controlling the rotor mechanical power. It also can be used for quasi-steady aerodynamic load control. Conventional pitch control systems are used to limit the rotor mechanical power at a its rated value and to optimise the energy capture below that value. Individual pitch control systems have been successfully developed and utilised to alleviate low-frequency fluctuating loads by pitching the blades individually (Caselitz 1997, Bossanyi 2003, Lovera 2003, Larsen 2005, van Engelen 2006). The concept of individual pitch control was first introduced for helicopter rotor blades (Johnson 1982). Still some disadvantages are evident, especially for the large scale application for wind turbine blades. The response time for individual pitch control systems is not fast enough for high frequency load fluctuation. Moreover, actuation of massive large blades requires significant actuation force and energy.

As a result of the significant growth of wind turbines in size, blade load control has become the main challenge for large wind turbines (Nijssen 2006, Johnson 2008 and Barlas 2010). Many advanced techniques have been investigated aiming at developing control devices to ease blade loading. Individual pitch control system, adaptive blades, trailing edge microtabs, morphing aerofoils, ailerons, trailing edge flaps, and telescopic blades are among these techniques. Generally speaking, power and blade load control can be carried out either through devices installed on blades (or blade itself), or via mechanism affecting the rotor as a whole. Figure 1 classifies and shows different conventional and nonconventional power and load control mechanisms affecting the blade performance. Some of these control systems respond only to wind variations with large time scales, while some other have shorter response time and therefore can be used for controlling the effect of wind variations with smaller time-scales.

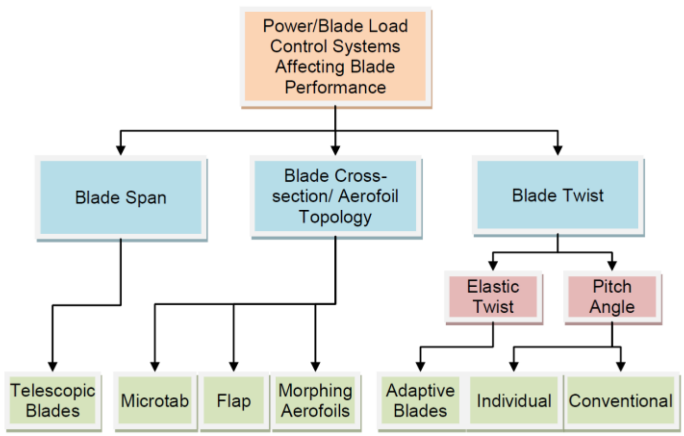

FIGURE 1-DIFFERENT CONTROL SYSTEMS AFFECTING BLADE PERFORMANCE

Adopting from the helicopter blade technology, passive blade twist control is a relatively new field in the wind turbine industry. This approach, known as adaptive or intrinsically smart blades, employs the blade itself as the controller to sense the wind velocity or rotor speed variations and adjust its aerodynamic characteristics to affect the wind turbine performance. Earlier work was carried out on the project at Reading University by Karaolis (1989) and Kooijiman (1996) and then progressed by other investigators. These blades are made of anisotropic composite materials and change their shapes in response to the variations in wind turbine operating conditions. It has been shown that these blades potentially can be used for both blade load alleviation and enhancing energy capture capabilities (Lobitz, 2001, Maheri 2006, Maheri et al 2006a, 2006b, 2007a, 2007b and 2007c, Maheri and Isikveren 2009, Maheri and Isikveren 2010 and Zhang 2013) .

A different kind of aerodynamic device proposed for load alleviation is microtabs (Baker and Mayda 2005, Chow 2007, van Dam et al 1999, Wiratama 2012, Wiratama and Maheri 2014, Macquart 2014, Macquart et al 2014 and Macquart and Maheri 2015). Microtabs are small aerodynamic control surfaces with deployment height of order of magnitude of 1% of local chord, installed close to the trailing edge of the blade.

Morphing blades, a concept adopted from aircraft morphing wings, has also the potential to improve the system performance over the wind turbine operational envelope (for example see Stuart 1997, Farhan 2008 and Barlas 2010). The morphing concept includes a wide spectrum of shape adaptations such as variation in camber, twist, span and plan form area. Camber control is a type of morphing aerofoils and an effective way of controlling the aerodynamic forces by directly changing the shape of the aerofoil. This action has direct effects on the force distribution on the blade, so it can be used for active load alleviation purposes (Farhan 2008, Maheri and Isikveren 2011).

Aileron is another concept borrowed from aerospace industry. It originally was used for aerodynamic breaking of wind turbines. Results of research on ailerons via simulating the behaviour of a wind turbine in turbulent wind indicates that aileron load control can assist in power regulation and reduce root flap bending moments during a step-gust and turbulent wind situation (Migliore 1995, Stuart 1996, Enenkl 2002).

The concept of trailing edge flap follows the same principle as aileron, but by deflecting the trailing edge portion of the aerofoil, to change the aerodynamic characteristics of the blade in high-wind conditions and turbulent wind (Troldborg and Buhl 2005, Andersen 2006, Wiratama 2012, Wiratama and Maheri 2014, Macquart 2014, Macquart et al 2014 and Macquart and Maheri 2015).

Recently, the concept of variable length blades has been also proposed as a means of controlling the load and increasing the energy yield of the turbine. Telescopic blades retract/extend in response to the variations in wind speed (DOE 2005, GE Wind Energy 2006, Pasupulapati 2005, Shrama 2007).

Figure 2 classifies smart blades into two categories, namely, intrinsically smart and extrinsically smart. This classification is associated with the type of control in place: passive control for intrinsically smart and active control for extrinsically smart blades.

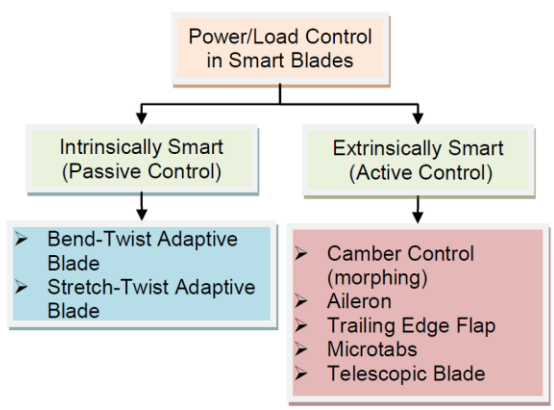

FIGURE 2- INTRINSICALLY AND EXTRINSICALLY SMART BLADES

SIMULATION

Aerodynamic load on blades and rotor mechanical power can be found via aerodynamic simulation of wind turbine. In intrinsically smart blades (adaptive blades), the aerodynamics of the blade is modelled in conjunction with the blade structural characteristics and, in case of unsteady analysis, the blade aeroelastic characteristics. In extrinsically smart blades, the aerodynamic of the blade is modelled integrated with the controller characteristics and, in case of unsteady analysis, the blade aeroelastic characteristics.

Intrinsically Smart Blades (Adaptive Blades)

Due to structure aerodynamic interaction in intrinsically smart blades, the aerodynamic performance simulation of these blades cannot be carried out independent of structural analysis as shown in Figure 3 (Maheri 2010).

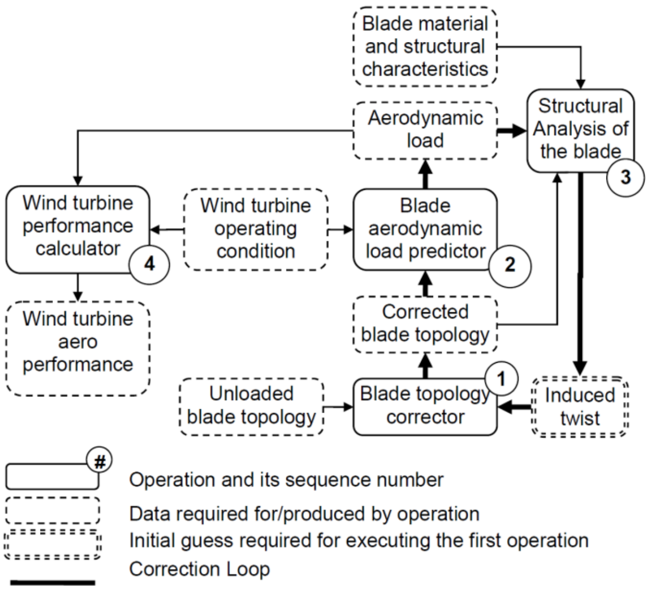

FIGURE 3-COUPLED AERO-STRUCTURE SIMULATION OF A WIND TURBINE WITH BEND-TWIST ADAPTIVE BLADES

WTAB (Wind Turbine Adaptive Blades) (Maheri et al 2006a) and its extended version (Maheri 2012), perform a complete aero-structural simulation (see Figure 4). This code consist of three main modules, namely, WTAero, the BEMT-based wind turbine aerodynamic analyser; ABMesh, the in-line adaptive mesh generator (Maheri 2007d); and TRIC, the natural mode formulated finite element solver. Figure 5 shows the data flow in a coupled aero-structure simulation in WTAB. While WTAB was proved to be very efficient and reliable in simulation of adaptive blades, including a finite element analysis (FEA) in an iterative process was the motivation of the development of WTSID (Wind Turbine Simulation and Integrated Design) (Wiratam 2012 and Zhang 2013). In contrary to WTAB, in which structural analysis is carried out via FEA, in WTSID the structural analyser is based on mathematical models (Zhang et al 2012a, 2012b, Zhang 2013 and Zhang and Maheri 2014). Figure 6 shows the cross section of a blade made of different materials, as in adaptive blades and Figure 7 shows the graphical user interface of Zhang's structural analyser in WTSID.

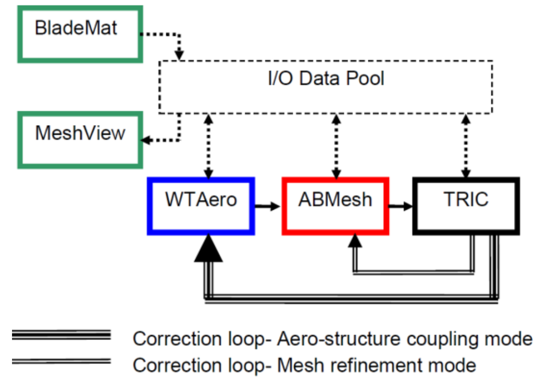

FIGURE4- COUPLED AERO-STRUCTURE ANALYSIS APPROACH, WTAB

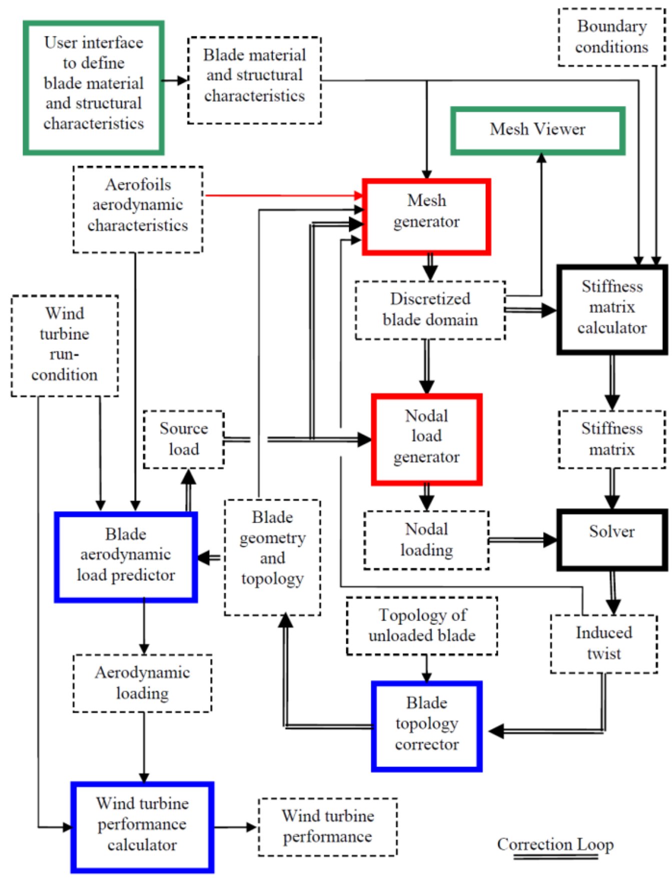

FIGURE 5- COUPLED AERO-STRUCTURE SIMULATION IN WTAB

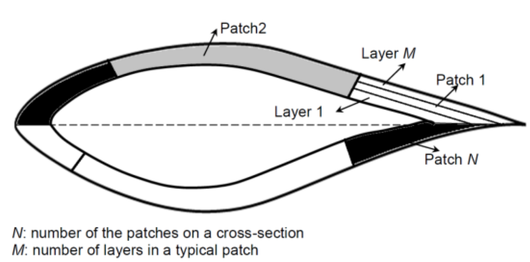

FIGURE 6-A TYPICAL CROSS-SECTION OF AN ADAPTIVE BLADE WITH *N* PATCHES

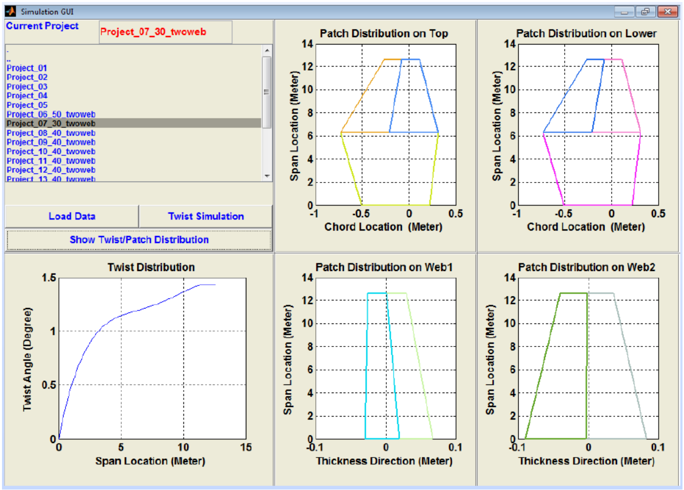

FIGURE 7-ZHANG'S ADAPTIVE BLADE STRUCTURAL ANALYSIS GRAPHICAL INTERFACE

Figures 8 and 9 show the results of a coupled aero-structure analysis of a 300kW AWT-27 wind turbine using adaptive blades operating at a steady wind speed of 10 m/s, rotor speed of 53.3 rpm and zero rotor yaw angle (Maheri 2012).

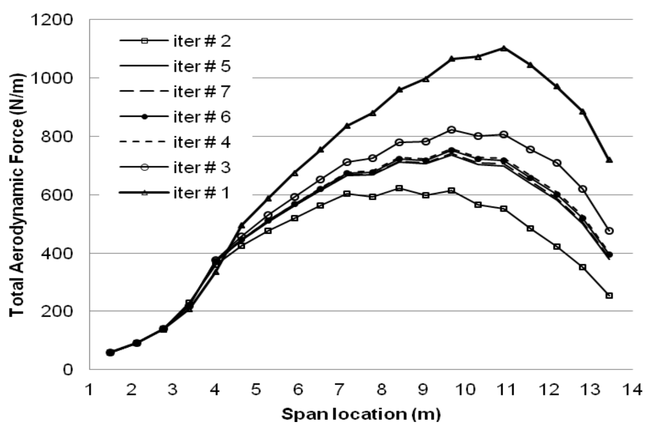

FIGURE 8-SPAN-WISE DISTRIBUTION OF TOTAL AERODYNAMIC FORCE AT ZERO AZIMUTH ANGLE

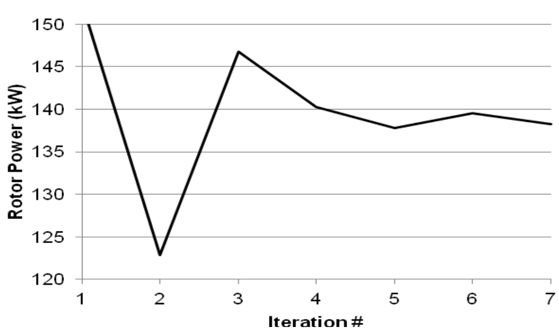

FIGURE 9- ROTOR MECHANICAL POWER AT 10 m/s

Extrinsically Smart Blades

In extrinsically smart blades, the aerodynamic performance depends on the characteristics of the control system in place (type, response time, controlling parameter, controllable parameter, etc) as well as the wind turbine rotor characteristics (e.g. blade topology and size, number of blades and rotor angular speed) and the operating condition (e.g. mean wind speed at hub elevation, wind direction and turbulence level). Hence, the performance of the controller itself should be properly integrated as part of the simulation process. Very few software tools developed for simulation of extrinsically smart blades, amongst them are WTSID for steady state simulation and WTAC (Macquart and Maheri 2015), which can perform both steady state and unsteady simulation. The approach taken for the integration of the controller into simulation is different.

a) Steady Simulation

In WTSID, the controller is simulated through solving an optimisation problem. It is assumed that the controller is capable of delivering the expected functions perfectly. This implies that the controlling parameter is always adjusted at its best possible value, which leads to the best (goal) performance. Adapting this approach, the optimum (best possible) controlling parameter, which optimises the performance measure(s) can be found via solving the optimisation problem of Equation 1 for power control and the optimisation problem of Equation 2 for load control:

$$\max \quad P(q_i);\ i=\{1,2,\ldots,n_q\} \tag{1.a}$$

subject to

$$P \le P_{rated} \tag{1.b}$$

$$q_{i,l} \le q_i \le q_{i,u}\,;\, i=\{1,2,\ldots,n_q\} \tag{1.c}$$

$$\min \quad L(q_i);\ i=\{1,2,\ldots,n_q\} \tag{2.a}$$

subject to

$$q_{i,l} \le q_i \le q_{i,u}\,;\, i=\{1,2,\ldots,n_q\} \tag{2.b}$$

where P is the rotor mechanical power at a given wind speed, L is a representative load (e.g. flap bending moment at the blade root), q_i stands for the i-th controlling parameter limited to the interval $[q_{i,l}, q_{i,u}]$. Number of independent controlling parameters, n_q depends on the type of the blade and the rotor (constant speed or variable speed).

The 300kW AWT-27 was taken as the case for study. This wind turbine is simulated with extrinsically smart blades instead of its original blades. The results of simulations are shown in Figures 10 through 15 (Wiratama 2012). The smart blades used for these simulations have the same topology (aerofoil, pretwist and chord distributions) as the original blades. With reference to these figures the following conclusions can be drawn.

- Using telescopic blades enhances the power capture capability significantly at lower wind speeds for both constant speed and variable speed rotors.
- Telescopic blades provide a full and smooth control.
- The bending moment at the root of the blade increases significantly by using telescopic blades.
- Microtab and flap have been initially developed for load alleviation purposes. These controlling devices, however, can be used to regulate and enhance the rotor mechanical power to some extent.
- Microtab and flap slightly improve the power coefficient for constant speed rotors.
- Although microtab is not as efficient as flap or pitch control systems, it increases the load on blades significantly when used for power enhancement.
- Flaps, when used in conjunction with another controlling system such as rotor speed, the accompanied controlling system dominates the control process. This conclusion can be extended to microtabs by observing similar effect of both controlling systems on the power curve.

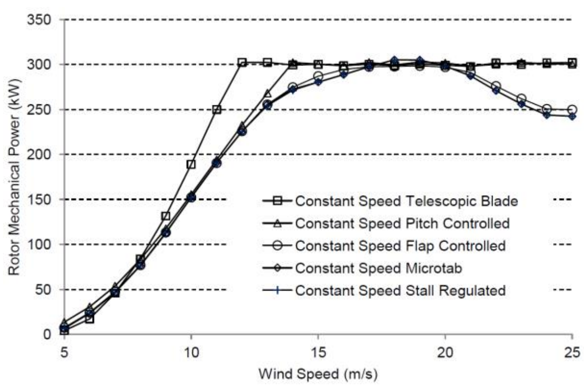

FIGURE 10-ROTOR POWER-CONSTANT SPEED

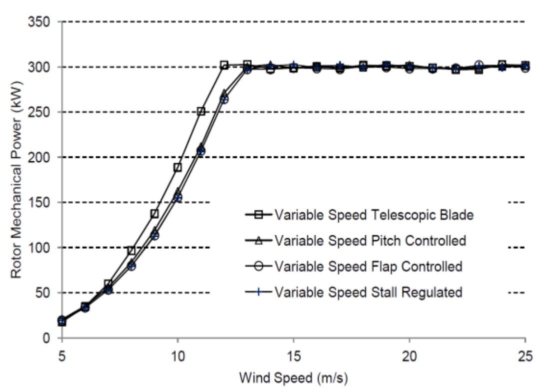

FIGURE 11-ROTOR POWER-VARIABLE SPEED

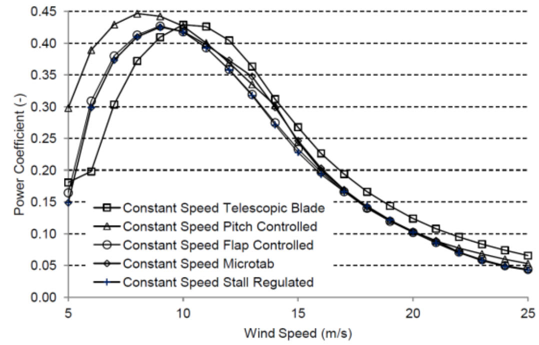

FIGURE 12-POWER COEFFICIENT-CONSTANT SPEED

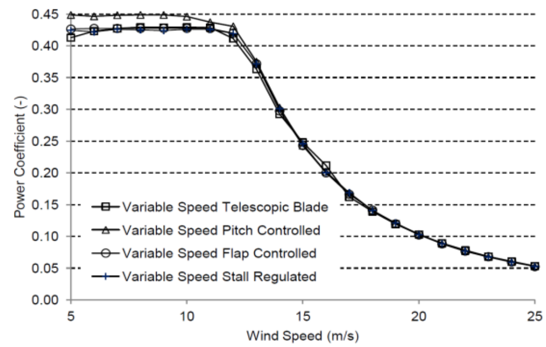

FIGURE 13-POWER COEFFICIENT-VARIABLE SPEED

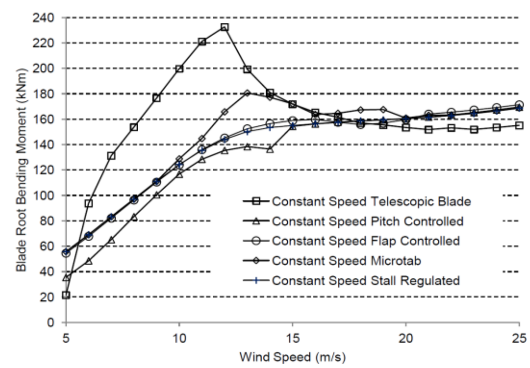

FIGURE 14-BLADE ROOT BENDING MOMENT-CONSTANT SPEED

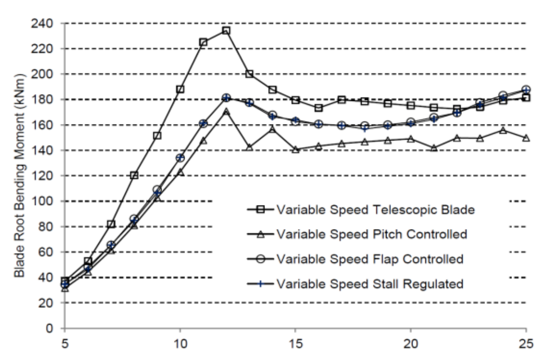

FIGURE 15- BLADE ROOT BENDING MOMENT-VARIABLE SPEED

b) Unsteady Simulation

In the second approach, as in WTAC, the controller is designed and implemented as part of the blade aeroelastic model. The overall model takes into account the interaction between the blade aerodynamic and its structure as well as the controller. Figure 15 demonstrate this interaction schematically and Figure 16 shows a typical control structure (Macquart 2014).

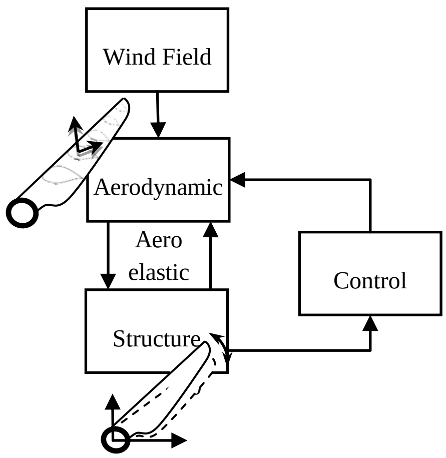

FIGURE 15-UNSTEADY SIMULATION OF EXTERINSICALLY SMART BLADES

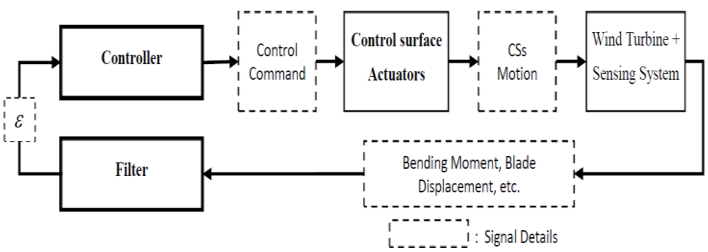

FIGURE 16 - TYPICAL EXTERINSICALLY SMART BLADES CONTROL STRUCTURE

In extrinsically smart blades, power and/or load control is due to changes in the aerodynamic characteristics of the blade, mainly as a result of sectional lift coefficient. Figure 17 shows typical variation of lift coefficient of an aerofoil due to the deployment of a control surface (flap or microtab).

The comparison between the original and controlled flapwise root bending experienced by the NREL 5 MW wind turbine blade is presented in Figure 18 (Macquart 2014).Reduction in dynamic load can have significant effect on the fatigue life of blades and other components of wind turbines Macquart and Maheri (2015). In Figure 18, the smart blade is equipped with multiple control surfaces employing P and PD controllers combined with high-pass filter.

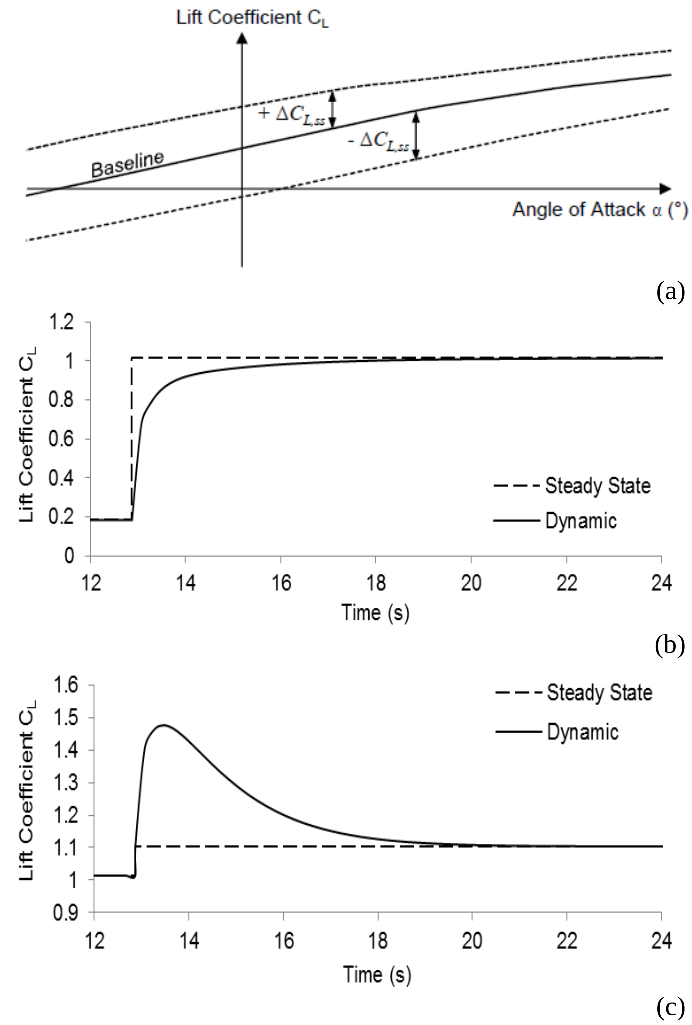

FIGURE 17 –TYPICAL VARIATION OF LIFT COEFFICIENT OF AN AEROFOIL DUE TO THE DEPLOYMENT OF ACONTROL SURFACE: (a) STEADY STATE, (b) DYNAMIC RESPONSE PRE-STALL AND (c) DYNAMIC RESPONSE POST STALL ANGLE OF ATTACK

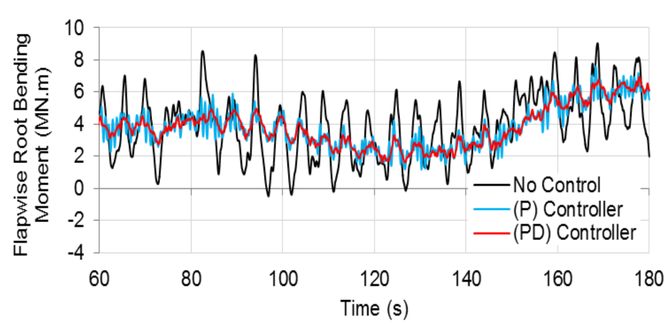

FIGURE 18-FLAPWISE ROOT BENDING MOMENT: MULTIPLE CONTROL SURFACE LOAD ALLEVIATION OF THE NREL 5MW WIND TURBINE BLADE USING P AND PD CONTROLLERS (18m/s TURBULENT WIND FIELD)

DESIGN APPROACHES

In design of smart blades, researchers take one of the following approaches:

- Retrofitting, in which elastic coupling or active devices are added to an existing blade design, without any modification to the blade topology.
- Modification, in which the original topology of the base design is modified
- Design from scratch

Examples of retrofitted designs include Figures 9-14 and 18 reported in this paper. Further modification of the wind turbines of Figures 9-14 using a genetic algorithm-based blade optimisation tool (Maheri and Isikveren 2009 and Wiratama 2012) leads to better performance of these blades. For example, see Figures 19 and 20. Figure 19 shows the modified pretwist of the blade of AWT-27 wind turbine. The pretwist of the blade is optimised towards maximising the wind turbine power extraction capability when flaps are installed along 25% of the span.

Not all of the modification-based designs employ an optimisation tool to find the optimum topology. Maheri et al (2006) presented a simple method for modifying a conventional blade to an adaptive blade without any search-based optimisation.

As adding more modifications to the original blade improves the performance of the smart blade, a design from scratch, in which there is no initial rigidity on the design space, is more likely to yield to the optimum solution. Design from scratch is more complicated than a modified base design. In a design from scratch, an integrated design approach should be taken. Figure 21 shows a schematic diagram of an integrated adaptive blade design (Maheri et al 2007a).

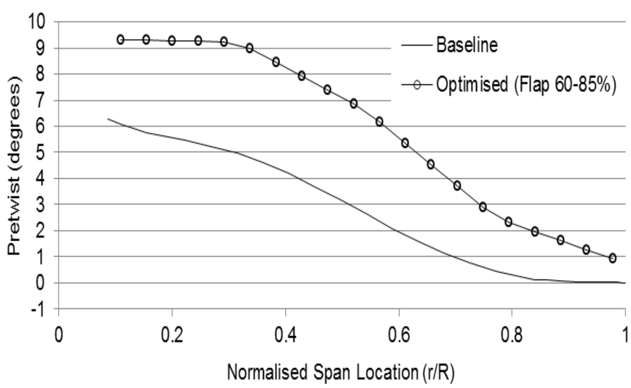

FIGURE 19-SMART BLADE EQUIPPED WITH TRAILING EDGE FLAPS WITH OPTIMISED PRETWIST

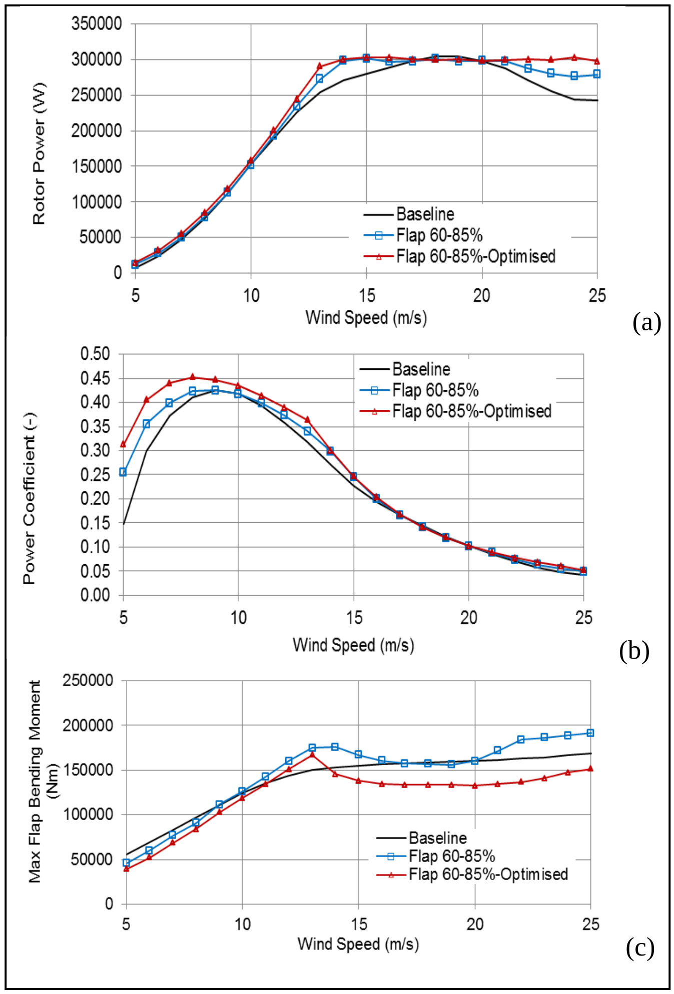

FIGURE 20-AWT-27 PERFORMANCE USING ORIGINAL BLADES, RETROFITTED SMART BLADES AND MODIFIED SMART BLADES

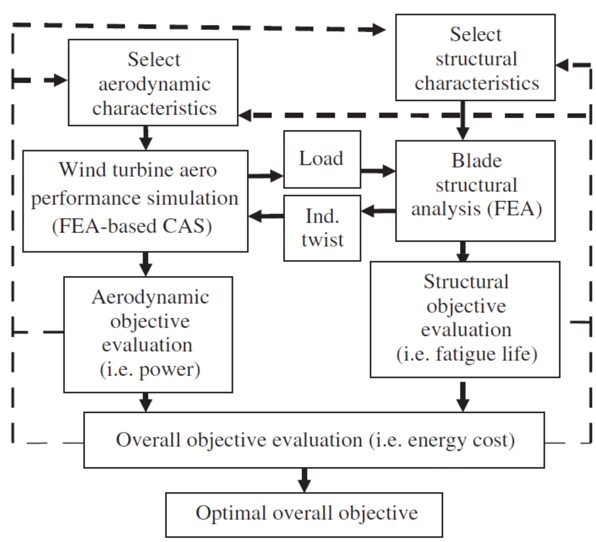

FIGURE 21 -ADAPTIVE BLADE INTEGRATED DESIGN PROCESS

ACKNOWLEDGMENT

The author would like to acknowledge the contribution of Dr I Kade Wiratama, Dr Hui Zhang and Dr Terence Macquart during their PhD study at Northumbria University in research on smart blades reported in this paper.

REFERENCES

1. Andersen P. B., Gaunaa . M. et al. (2006) Load alleviation on wind turbine blades using variable airfoil geometry. In: Proceedings of European Wind Energy Conference and Exhibition2006, Athens.
2. Barlas, T. & Van Kuik, G. M. (2010) Review of state of the art in smart rotor control research for wind turbines. Aerospace Sciences, 46, 1-27.
3. Bossanyi, E. (2003) Individual blade pitch control for load reduction. Wind Energy, 6, 119–128.
4. Baker, J. P., Standish, K. J. & van Dam, C. P. (2005) Two-dimensional wind tunnel and computational investigation of a microtab modified S809 airfoil, AIAA 2005-1186. In: Proceedings of the 43rd AIAA/ASME, Reno, NV, USA.
5. Caselitz, P., Kleinkauf, W., Krueger, W., Petschenka, J., Reichardt, M., & Stoerzel K. (1997). Reduction of fatigue loads on wind energy converters by advanced control methods. In: European Wind Energy Conference, Dublin. Pages 555–558.
6. Chow, R. & van Dam, C.P. (2007) Computational investigations of deploying load control microtabs on a wind turbine airfoil. In: Proceedings of the 45th AIAA/ASME, Reno, NV, USA.
7. Enenkl, B., Klopper, V. et al. (2002) Full scale rotor with piezoelectric actuated blade flaps. In: 28th European Rotorcraft Forum.
8. Farhan, G. & Phuriwat, A. I. (2008) Skin design studies for variable camber morphing airfoils. IOPP'S Journal.
9. Johnson, W. (1982) Self-Tuning regulators for Multicyclic Control of Helicopter vibration. NASA-TP-1996, March 1982.
10. Karaolis, N. M., Jeronimidis, G. & Mussgrove, P. J. (1989) Composite wind turbine blades: coupling effects and rotor aerodynamic performance. In: Proceedings of EWEC'89, European Wind Energy Conference, Glasgow, Scotland, 1989.
11. Kooijman, H. J. T. (1996) Bending-Torsion Coupling of a Wind Turbine Rotor Blade, ECN-I 96- 060, Netherlands Energy Research Foundation ECN.
12. Larsen, T., Madson, H. & Thomson, K. (2005) Active load reduction using individual pitch, based on local blade flow measurements. Wind Energy, 8, 67–80.
13. Lobitz, D. W., Veers, P. S., Eisler, G. R., Laino, D. J., Migliore, P. G. & Bir, G. (2001) The Use of Twist-Coupled Blades to Enhance the Performance of Horizontal Axis Wind Turbines. Sandia National Laboratories, Report SAND2001-1003, May 2001.
14. Lovera, M., Colaneri, P., Malpica, C. & Celi, R. (2003) Closed-loop stability analysis of HHC and IBC, with application to a hinge less rotor helicopter. In: 29th European Rotorcraft Forum.
15. Macquart, Terence (2014) Aeroelastic Analysis of Wind Turbine Smart Blades Utilising Multiple Control Surfaces, PhD thesis, Northumbria University
16. Macquart, Terence, Maheri, Alireza and Busawon, Krishna (2014) Microtab dynamic modelling for wind turbine blade load rejection. Renewable Energy, 64. pp. 144-152. ISSN 0960-1481
17. Macquart, Terence, Maheri, Alireza and Busawon, Krishna (2014) A simple method to determine the optimal location of active flow controllers on wind turbine blades. In: 3rd International Symposium On Environment Friendly Energies And Applications (EFEA 2014), 19-21 Nov 2014, Paris.
18. Macquart, Terence and Maheri, Alireza (2015) Integrated aeroelastic and control analysis of wind turbine blades equipped with microtabs. Renewable Energy, 75. pp. 102-114. ISSN 0960-1481
19. Maheri, Alireza (2006) Aero-structure Simulation and Aerodynamic Design of Wind Turbines Utilising Adaptive Blades, PhD Thesis, University of the West of England-Bristol
20. Maheri, Alireza, Noroozi, Siamak, Toomer, Chris and Vinney, John (2006) WTAB, a computer program for predicting the performance of horizontal axis wind turbines with adaptive blades. Renewable Energy, 31 (11). pp. 1673-1685. ISSN 0960-1481
21. Maheri, Alireza, Noroozi, Siamak, Toomer, Chris and Vinney, John (2006) A simple algorithm to modify an ordinary wind turbine blade to an adaptive one. In: European Wind Energy Conference, 27 February-2 March 2006, Athens.
22. Maheri, Alireza, Noroozi, Siamak and Vinney, John (2007) Application of combined analytical/FEA coupled aero-structure simulation in design of wind turbine adaptive blades. Renewable Energy, 32 (12). pp. 2011-2018. ISSN 0960-1481
23. Maheri, Alireza, Noroozi, Siamak and Vinney, John (2007) Combined analytical/FEA-based coupled aero structure simulation of a wind turbine with bend–twist adaptive blades. Renewable Energy, 32 (6). pp. 916-930. ISSN 0960-1481
24. Maheri, Alireza, Noroozi, Siamak and Vinney, John (2007) Decoupled aerodynamic and structural design of wind turbine adaptive blades. Renewable Energy, 32 (10). pp. 1753-1767. ISSN 0960-1481
25. Maheri, Alireza, Noroozi, Siamak, Toomer, Chris and Vinney, John (2007) Efficient meshing of a wind turbine blade using force adaptive mesh sizing functions. Renewable Energy, 32 (1). pp. 95-104. ISSN 0960-1481

26. Maheri, Alireza and Isikveren, Askin (2009) Design of wind turbine passive smart blades. In: European Wind Energy Conference (EWEC 2009), 16-19 March 2009, Marseille, France.
27. Maheri, Alireza and Isikveren, Askin (2010) Performance prediction of wind turbines utilizing passive smart blades: approaches and evaluation. Wind Energy, 12 (2/3). pp. 255-265. ISSN 1095-4244
28. Maheri, Alireza and Isikveren, Askin (2011) Design of a single-DOF kinematic chain using hybrid GA-pattern search and sequential GA. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 226 (6). pp. 1633-1643. ISSN 0954-4062
29. Maheri, Alireza (2012) A finite element suite for deformation analysis of composite aeroelastic structures subjected to operational aerodynamic loading. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 226 (8). pp. 2062-2076. ISSN 0954-4062
30. Migliore, P. G., Quandt, G. A., et al. (1995) Wind turbine trailing edge aerodynamic brakes. National Renewable Energy Laboratory. Report number: NREL/TP-441-7805.
31. Stuart, J. G., Wright, A. D. & Butterfield, C. P. (1996) Considerations for an integrated wind turbine controls capability at the national wind technology centre: an aileron control case study for power regulation and load mitigation. National Renewable Energy Laboratory, Technical Report NREL/TP-440-21335.
32. Stuart, J. G., Wright, A. D., et al. (1997) Wind turbine control systems: dynamic model development using system identification and the fast structural dynamics code. In: Proceedings 35th AIAA/ASME.
33. Stylianidis, Nearchos, Macquart, Terence and Maheri, Alireza (2014) Aerodynamic design of wind turbine blades considering manufacturing constraints. In: 3rd International Symposium On Environment Friendly Energies And Applications (EFEA 2014), 19-21 Nov 2014, Paris.
34. Troldborg, N. (2005) Computational study of the risø-b1-18 aerofoil with a hinged flap providing variable trailing edge geometry. Wind Engineering, 29(2), 89-113.
35. van Engelen, T. (2006) Design Model and Load Reduction Assessment for Multi-rotational Mode Individual Pitch Control (Higher Harmonics Control). In: European Wind Energy Conference. Athens, Greece.
36. Van Dam, C. P., Yen, D. T. & Vijgen, P. M. (1999). Gurney flap experiments on airfoil and wings. Journal of aircraft, 36, 484-486.
37. Van Dam, C. P., Nakafuji, D. Y., Bauer, C., Chao, D. & Standish, K. (2002). Computational Design and Analysis of a Microtab Based Aerodynamic Loads Control System for Lifting Surfaces. SPIE International Society for Optical Engineers.
38. Wiratama, I. Kade and Maheri, Alireza (2011) An investigation into the potential use of microtabs in enhancing energy capture capability of wind turbines. In: 12th International Conference on QiR (Quality in Research), 4 July - 7 July 2011, Bali, Indonesia.
39. Wiratama, IKade (2012) Aerodynamic Design of Wind Turbine Blades Utilising Nonconventional Control Systems, PhD thesis, Northumbria University
40. Wiratama, I. Kade and Maheri, Alireza (2014) Optimal design of wind turbine blades equipped with flaps. ARPN Journal of Engineering and Applied Sciences , 9. pp. 1511-1515. ISSN 1819-6608
41. Zhang, Hui, Maheri, Alireza, Daadbin, Ali and Hackney, Philip (2012) Effect of laminate configuration and shell-thickness variation on the inducted twist distribution in wind turbine adaptive blades. In: 2012 2nd International Symposium On Environment Friendly Energies and Applications. IEEE, Piscataway, pp. 415-420. ISBN 978-1467329095
42. Zhang, Hui, Maheri, Alireza, Daadbin, Ali and Hackney, Philip (2012) An analytical model for deformation analysis of wind turbine adaptive blades. In: High Performance Structure and Materials VI. WIT transactions on the built environment, 124 . WIT Press, Southampton, UK, pp. 13-26. ISBN 978-1845645960
43. Zhang, Hui, Maheri, Alireza, Daadbin, Ali and Hackney, Philip (2012) An analytical model for frequency analysis of composite wind turbine blades. In: 2012 2nd International Symposium On Environment Friendly Energies and Applications. IEEE, Piscataway, pp. 415-420. ISBN 978-1467329095
44. Zhang, Hui (2013) Wind Turbine Adaptive Blade Integrated Design and Analysis, PhD thesis, Northumbria University
45. Zhang, Hui and Maheri, Alireza (2014) A software tool for optimising structural and material configurations of wind turbine adaptive blades. In: 3rd International Symposium On Environment Friendly Energies And Applications (EFEA 2014), 19-21 Nov 2014, Paris.