

on the BEM theory solved through a fixed-point algorithm. The optimisation algorithm used is a genetic based algorithm called NSGA-II.

The results of the optimisation process provides a wide range of WT. These WT are the best compromises between power and mass. Two WTs that are close in term of output power can present significantly differences in term of mass. Conversely, some WT close in term of mass can present differences in term of power. These results could be found thanks to the non-weighting of the objectives. Results also show a diversity in terms of parameters. We can have significantly different parameters WT that presents sensibly the same performances in terms of mass and power. These differences can occur between two or three of the parameters. This results in a great flexibility for both designer and manufacturer of WT.

It is possible to define other objective functions or parameters. Coupling power output depending on wind power with the probability distribution of a wind speed to occur would provide the AEP for each design of WT. In a context of performance depending on the incident wind, control actions of the WT such as load control and/or pitch angle control can be implemented in the algorithm to ensure an optimal AEP. This approach may be subject of future work.

Acknowledgement

The Region SUD (France) supported this work. The authors gratefully acknowledge this support.

References

- [1] Roberto Turconi, Alessio Boldrin, Thomas Astrup, Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations, *Renewable and Sustainable Energy Reviews*, Volume 28, 2013, Pages 555-565, ISSN 1364-0321, <https://doi.org/10.1016/j.rser.2013.08.013>.
- [2] Jureczko, M. & Pawlak, Mariusz & Mężyk, Arkadiusz. (2005). Optimization of Wind Turbine Blades. *Journal of Materials Processing Technology*. 167. 463-471. [10.1016/j.jmatprotec.2005.06.055](https://doi.org/10.1016/j.jmatprotec.2005.06.055).
- [3] A.F.P. Ribeiro, A.M. Awruch, H.M. Gomes, An airfoil optimization technique for wind turbines, *Applied Mathematical Modelling*, Volume 36, Issue 10, 2012, Pages 4898-4907, ISSN 0307-904X, <https://doi.org/10.1016/j.apm.2011.12.026>.
- [4] J. G. Sloopweg, H. Polinder and W. L. Kling, "Dynamic modelling of a wind turbine with doubly fed induction generator," 2001 Power Engineering Society Summer Meeting. Conference Proceedings (Cat. No.01CH37262), 2001, pp. 644-649 vol.1, doi: 10.1109/PSS.2001.970114.
- [5] Seul-Ki Kim, Eung-Sang Kim, Jae-Young Yoon and Ho-Yong Kim, "PSCAD/EMTDC based dynamic modeling and analysis of a variable speed wind turbine," IEEE Power Engineering Society General Meeting, 2004., 2004, pp. 1735-1741 Vol.2, doi: 10.1109/PES.2004.1373174.
- [6] Wang, Lin & Liu, Xiongwei & Kolios, Athanasios, 2016. "State of the art in the aeroelasticity of wind turbine blades: Aeroelastic modelling," *Renewable and Sustainable Energy Reviews*, Elsevier, vol. 64(C), pages 195-210.
- [7] A. Chehouri et al. "Review of performance optimization techniques applied to wind turbines," *Applied Energy*, vol. 142. Elsevier BV, pp. 361-388, Mar. 2015. doi: 10.1016/j.apenergy.2014.12.043.
- [8] Eke, G & Onyewudiala, J. (2010). Optimization of Wind Turbine Blades Using Genetic Algorithm. *Global Journal of Researches in Engineering*. 10.
- [9] Kevin Maki, Ricardo Sbragio, Nickolas Vlahopoulos, System design of a wind turbine using a multi-level optimization approach, *Renewable Energy*, Volume 43, 2012, Pages 101-110, ISSN 0960-1481, <https://doi.org/10.1016/j.renene.2011.11.027>
- [10] B. Bavanish, K. Thyagarajan, Optimization of power coefficient on a horizontal axis wind turbine using bem theory, *Renewable and Sustainable Energy Reviews*, Volume 26, 2013, Pages 169-182, ISSN 1364-0321, <https://doi.org/10.1016/j.rser.2013.05.009>.
- [11] Liu, X., Chen, Y. & Ye, Z. Optimization model for rotor blades of horizontal axis wind turbines. *Front. Mech. Eng. China* 2, 483-488 (2007). <https://doi.org/10.1007/s11465-007-0084-9>
- [12] Jin Chen, Quan Wang, Wen Zhong Shen, Xiaoping Pang, Songlin Li, Xiaofeng Guo, Structural optimization study of composite wind turbine blade, *Materials & Design*, Volume 46, 2013, Pages 247-255, ISSN 0261-3069, <https://doi.org/10.1016/j.matdes.2012.10.036>.
- [13] Giguere, Philippe & Selig, Michael. (2000). Blade geometry optimization for the design of wind turbine rotors. 10.2514/6.2000-45.
- [14] Bottasso, Carlo & Campagnolo, Filippo & Croce, Alessandro. (2012). Multi-disciplinary constraint optimization of wind turbines. *Multibody System Dynamics*. 27. 21-53. 10.1007/s11044-011-9271-x.
- [15] Venter, G. (2010). Review of Optimization Techniques. In *Encyclopedia of Aerospace Engineering* (eds R. Blockley and W. Shyy). <https://doi.org/10.1002/9780470686652.eae495>
- [16] K. Deb et al "A Fast Elitist Non-dominated Sorting Genetic Algorithm for Multi-objective Optimization: NSGA-II," *Parallel Problem Solving from Nature PPSN VI*. Springer Berlin Heidelberg, pp. 849-858, 2000. doi: 10.1007/3-540-45356-3_83
- [17] Yusliza Yusoff, Mohd Salihin Ngadiman, Azlan Mohd Zain, Overview of NSGA-II for Optimizing Machining Process Parameters, *Procedia Engineering*, Volume 15, 2011, Pages 3978-3983, ISSN 1877-7058, <https://doi.org/10.1016/j.proeng.2011.08.745>.
- [18] Hansen, M. (2015). *Aerodynamics of Wind Turbines* (3rd ed.). Routledge. <https://doi.org/10.4324/9781315769981>
- [19] Liu, S., Janajreh, I. Development and application of an improved blade element momentum method model on horizontal axis wind turbines. *Int J Energy Environ Eng* 3, 30 (2012). <https://doi.org/10.1186/2251-6832-3-30>
- [20] Jin, M, Yang, X. A new fixed-point algorithm to solve the blade element momentum equations with high robustness. *Energy Sci Eng*. 2021; 9: 1734-1746. <https://doi.org/10.1002/ese3.945>
- [21] Branlard, Emmanuel. (2017). The blade element momentum (BEM) method. 10.1007/978-3-319-55164-7_10.
- [22] FINGERSH, L., HAND, Maureen, et LAXSON, A. Wind turbine design cost and scaling model. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2006.
- [23] Garambois, Pierre & Perret-Liaudet, Joël & Rigaud, Emmanuel. (2017). NVH robust optimization of gear macro and microgeometries using an efficient tooth contact model. *Mechanism and Machine Theory*. 117. 78-95. 10.1016/j.mechmachtheory.2017.07.008.