energies

MDPI

Editorial

Wind Turbine Performance Decline with Age

Davide Astolfi [1,*] and Ravi Pandit [2]

[1] Department of Engineering, University of Perugia, Via G. Duranti 93, 06125 Perugia, Italy
[2] Centre for Life-Cycle Engineering and Management (CLEM), School of Aerospace Transport and Manufacturing, Cranfield University, Bedford MK43 0AL, UK; ravi.pandit@cranfield.ac.uk
* Correspondence: davide.astolfi@studenti.unipg.it

Wind turbines, as any technical system, are expected to have an efficiency that declines in time. Since wind turbines are complex machines subjected to non-stationary operation conditions, there are no theoretical standards defining within what extent the aging should affect the performance. Nevertheless, this is an important aspect for an accurate assessment of wind farms' profitability and it is fundamental to deal with it for a deeper exploitation of renewable energy.

Based on this, the unique possibility for estimating wind turbine performance decline with age is learning from experience, which means from data. This has become feasible due to the large amounts of wind turbines reaching the end of lifetime expectancy: Actually, there are peaks of 50% of wind turbines with 15 or more years in Spain, Germany and Denmark.

The estimation of wind turbine performance decline with age has, therefore, recently attracted a certain amount of attention in the scientific literature, which is reviewed and discussed in the present editorial. Substantially, two different approaches to the problem can be individuated:

- The use of cumulative data of the highest possible number of wind farms;
- The use of detailed data sets, which means SCADA-collected, for a limited amount of instructive test cases.

The rationale for employing the former approach is that the results are expected to be more general, but the drawback is the lack of control and interpretation; vice versa for the latter.

Literature Based on Cumulative Data Analysis

In [1], 282 wind farms sited in the U.K. have been analyzed and the proposed method is substantially a regression between the age and the capacity factor. The achieved estimate is that the considered wind farms lose $1.6 \pm 0.2\%$ of output per year. It should be noticed that the study was published in 2014, which means that the employed cumulative data likely refer to wind turbines with rotor diameter in the order of 40–50 m.

The study in [2] deals with Swedish wind farms and is also based on age—capacity factor regression. The reported average estimate is -0.1 capacity factor per year. With this study, a distinction between older and newer wind turbines starts being introduced, which in this case is quite counterintuitive: wind turbines installed before 2007 show a decline in the order of -0.15% per year, roughly corresponding to 6% of energy loss in a twenty years lifetime, while newer wind turbines, having larger average capacity factor, are hinted to be affected by sharper decline.

In [3], monthly capacity factor data of 921 wind farms sited in Germany are analyzed. The results shed light on the effect of evolving technology and of aging: The average capacity of the considered fleet was 611 kW in 2000, increasing to 1453 kW in 2014. The average estimate of performance decline with age is -0.63% per year and the losses with respect to the ideal yield are shown to increase from 3.75% in the year 2000 to 6.70% in the year 2014. Correspondingly, the average capacity factor is shown to have a little decline in

check for updates

Citation: Astolfi, D.; Pandit, R. Wind Turbine Performance Decline with Age. *Energies* **2022**, *15*, 5225. https://doi.org/10.3390/en15145225

Received: 8 July 2022
Accepted: 18 July 2022
Published: 19 July 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

the latest considered years: this means that the decline for the aged wind turbines was slightly overwhelming with respect to the increase due to the installation of newer and larger rotors.

The same kind of analysis is performed in [4] for 917 wind farms sited in the U.S. for their first ten years of operation. A distinguishing aspect of this study is that the age—capacity factor regression is also run separately for plants installed before or after the year 2008 and it arises that the former averagely lose −0.5% of performance per year, while the latter lose −0.17%. For older plants, the so-called year-10 drop is studied, which is defined as the difference in performance between years 8–10 and 11–13: this is estimated to be the remarkable quantity of −1.23% per year.

The study in [5] deals with 26 offshore wind farms sited in the U.K., for which annual capacity factor data have been analyzed in the years 2005–2018. The estimate is that no statistically significant decline is visible, which apparently contradicts the findings of the previously cited papers. Actually, the results might be coherent because in [5], it is shown that the age of the considered fleet is quite low and, in fact, the rotor diameter of the considered wind turbines proceeds from 80 to 164 m. Therefore, the decline rate might have been estimated to vanish because the technology evolution mitigates the effect of aging and because, in any case, such an effect is expected to be negligible at least for the first five years of operation.

In [6], the wind generation fleet in Texas is studied. The speculation is that the decline rate is practically flat for the first years of operation and it accelerates thereon, irrespective of the wind turbine size. This means that aging occurs similarly for wind turbines having 50 or 150 rotor diameter, but of course in the latter case, the economic impact is less in percentage.

Literature Based on SCADA Data Analysis

The first study dealing with the use of Supervisory Control And Data Acquisition (SCADA) data for the analysis of wind turbine performance decline with age is [7]. Four criteria are formulated, which are based, respectively, on the assessment of the stability of produced power above rated speed, of the behaviour of the power coefficient C_p and of the individuation of anomalous nacelle vibrations and sub-components heating.

Subsequently, several studies have been devoted to an in deep investigation of a Vestas V52 installed in October 2005 at the Dundalk Institute of Technology in Ireland. In [8], data from the years 2008 up to 2019 have been analyzed and an interesting aspect of the case study is that the gearbox of the wind turbine reached the end of life in October 2018: Therefore, with ad hoc analyses, it has been possible to speculate on the effect of the different components on the performance decline with age. Using the binning method for the power curve recommended by the International Electrotechnical Commission and employing a data-driven multivariate method, it arises that the performance decline mainly manifests when the wind turbine is aged 12 years. Actually, the energy yield below rated power in 2017 (12 years of age) is estimated to be −6.2% less than that estimated from the data of the year 2007. Upon the replacement of the gearbox, a slight recovery is observed but this does not compensate the overall losses due to the ageing.

The same test case is investigated more in deep in the subsequent work in [9]: operation curves different from the power curve have been employed in order to understand how the performance decline with age manifests. Through the analysis of the rotor speed power curve, it arises that the performance decline can be mainly ascribed to the decrease in power extracted for a given rotational speed. Sideways, the results of [9] support that ad hoc SCADA data analysis methods are necessary for an in deep comprehension of wind turbine performance.

Given the results collected in [9], two lines of investigation follow: the former deals with the comprehension of how general the observed behaviour is and the latter deals with the interpretation of the root causes of the performance decline with age.

In [10], further cases of Vestas V52 wind turbines from a wind farm in southern Italy are analyzed and compared against the Dundalk one. It arises that, for none of them, a

10-year decline as for the Dundalk case occurs, and the conclusion is, therefore, that the aging depends considerably on the history of the wind turbine, and it is difficult to claim that one size fits all.

The rationale of the study in [11] is also the analysis of further test cases, but of different wind turbine model types, based on which it has been hypothesized that the type of technology is the factor mostly determining the possible pattern of performance decline with age, rather than the wind turbine size. Actually, in [11], it is shown that wind turbines with hydraulic pitch control can reach performance decline rates which are much higher than those observed for electrically controlled machines and which are due mainly to diminished extracted power for a given rotational speed. This is compatible with a worsening of the hydraulic pitch actuators' response time, which likely induces a non-optimal working point of the wind turbine and a non-optimal $C_p - \lambda$ curve.

Therefore, the lesson from the above summarized studies is that likely there is a trade-off: the electrical control of blade pitch might guarantee higher performance stability in time at the cost of higher failure rate and vice versa for the hydraulic pitch control. This hypothesis should be analyzed more in deep through the study of a vast statistics of case studies and a deeper comprehension of the behaviour of the blade pitch. For example, in [12], an attempt is formulated at assessing the ageing of the electrical blade pitch component by taking into account indicators partially similar to those formulated in [7]: power coefficient C_p, power stability above rated speed, pitch motor energy consumption and heating, failure rates. It would be interesting to do a similar study for hydraulic blade pitch cases.

A further SCADA-based study of performance decline with age is given in [13]: LiDAR and SCADA data are employed for the analysis of the behaviour of three Mitsubishi MWT-1000A wind turbines for the first four years of operation and the achieved estimate is an average decline of -0.52% per year, which is higher than the plausible expectations based on the reasoning of [6].

In [14], wind turbines sited in Norway are analyzed, having 2 MW of rated power and 82 m of rotor diameter. A feature selection algorithm is employed in order to individuate the covariates of the data-driven model for the power of the target wind turbines, which is based on deep neural networks. The ageing is quantified by comparing the estimated against measured average wind turbine efficiency in the period from 2007 to 2017 and the reported result is -0.64% per year.

Research Directions

From the above discussion, it arises that the literature about wind turbine performance decline with age has recently been developing and has stimulated a certain number of observations which can be useful for the improvement of wind turbine management.

The definition of ageing has fleeting borders because the performance decline is observed to impact differently the various wind turbines: Most wind turbines are observed to have a decline rate, which is almost negligible and few turbines (with hydraulic pitch control, as far as the results in the literature at present support) are observed to have remarkable losses with respect to the ideal yield. Can the former and the latter be considered aging effects on an equal footing or is the latter more appropriate to be defined as malfunctioning or incoming fault? Whatever the answer to the above question is, it is evident that the identification of the mechanisms leading in turn to wind turbine performance decline with age should be analyzed more in deep, in order to individuate counteracting strategies and finally maintain wind turbine efficiency as much as possible throughout all the lifetime. Furthermore, it should be clarified that by the point of view of the energy yield, the trade off between performance and reliability of the different types of wind turbine technologies is non-trivial and should be investigated in detail in future works.

Much attention in the wind energy literature has been devoted to gears and bearings condition monitoring, because damages to these components are critical especially for offshore installations. Nevertheless, an emerging trend in the literature regards the moni-

toring of the rotor and the considerations collected in this paper about the blade pitch as a critical component further support this point of view.

Author Contributions: The authors have contributed equally to the work: D.A. and R.P. All authors have read and agreed to the published version of the manuscript .

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Staffell, I.; Green, R. How does wind farm performance decline with age? *Renew. Energy* **2014**, *66*, 775–786. [CrossRef]
2. Olauson, J.; Edström, P.; Rydén, J. Wind turbine performance decline in Sweden. *Wind Energy* **2017**, *20*, 2049–2053. [CrossRef]
3. Germer, S.; Kleidon, A. Have wind turbines in Germany generated electricity as would be expected from the prevailing wind conditions in 2000–2014? *PLoS ONE* **2019**, *14*, e0211028. [CrossRef] [PubMed]
4. Hamilton, S.D.; Millstein, D.; Bolinger, M.; Wiser, R.; Jeong, S. How does wind project performance change with age in the United States? *Joule* **2020**, *4*, 1004–1020. [CrossRef]
5. Benini, G.; Cattani, G. Measuring the long run technical efficiency of offshore wind farms. *Appl. Energy* **2022**, *308*, 118218. [CrossRef]
6. Fitzgerald, T.; Giberson, M. Wind project performance with age: Policy, technology, markets, and the maturing wind power industry. *Electr. J.* **2021**, *34*, 107047. [CrossRef]
7. Dai, J.; Yang, W.; Cao, J.; Liu, D.; Long, X. Ageing assessment of a wind turbine over time by interpreting wind farm SCADA data. *Renew. Energy* **2018**, *116*, 199–208. [CrossRef]
8. Byrne, R.; Astolfi, D.; Castellani, F.; Hewitt, N.J. A Study of Wind Turbine Performance Decline with Age through Operation Data Analysis. *Energies* **2020**, *13*, 2086. [CrossRef]
9. Astolfi, D.; Byrne, R.; Castellani, F. Analysis of Wind Turbine Aging through Operation Curves. *Energies* **2020**, *13*, 5623. [CrossRef]
10. Astolfi, D.; Byrne, R.; Castellani, F. Estimation of the Performance Aging of the Vestas V52 Wind Turbine through Comparative Test Case Analysis. *Energies* **2021**, *14*, 915. [CrossRef]
11. Astolfi, D.; Pandit, R.; Celesti, L.; Vedovelli, M.; Lombardi, A.; Terzi, L. Data-Driven Assessment of Wind Turbine Performance Decline with Age and Interpretation Based on Comparative Test Case Analysis. *Sensors* **2022**, *22*, 3180. [CrossRef] [PubMed]
12. Wei, L.; Qian, Z.; Zareipour, H.; Zhang, F. Comprehensive aging assessment of pitch systems combining SCADA and failure data. *IET Renew. Power Gener.* **2022**, *16*, 198–210. [CrossRef]
13. Kim, H.G.; Kim, J.Y. Analysis of Wind Turbine Aging through Operation Data Calibrated by LiDAR Measurement. *Energies* **2021**, *14*, 2319. [CrossRef]
14. Mathew, M.S.; Kandukuri, S.T.; Omlin, C.W. Estimation of Wind Turbine Performance Degradation with Deep Neural Networks. In Proceedings of the PHM Society European Conference, Turin, Italy, 6–8 July 2022; Volume 7, pp. 351–359.



https://dspace.org/

Wind turbine performance decline with age

Astolfi, Davide; Pandit, Ravi

2022-07-19
MDPI
https://doi.org/10.3390/en15145225
Astolfi D, Pandit R. (2022) Wind turbine performance decline with age, Energies, Volume 15, Issue 14, July 2022, Article number 5225

Downloaded from a DSpace repository. https://dspace.org/