Wind Turbine Blades: End-of-Life Scenarios

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Contributor: Leon Mishnaevsky Jr.

Large expansion of wind energy is expected in next decades. At the same time, a significant proportion of the installed wind turbines, the generation installed in 2000s, will come to the end of their lifetime between 2020 and 2030. Many parts of wind turbines can be recycled, however, this is seldom the case for the composite wind blades. Wind turbine blades are developed and designed to sustain challenging service conditions and extraordinary mechanical and ennvironmental loads for several decades. Therefore, their afterlife destruction and separation into re-usable elements represents a challenge. In this review, strategies of end-of-life management of wind turbine blades are discussed. Various scenarios of end-of-life management of wind turbine blades are considered. “Reactive” strategies, designed to deal with ageing turbines, installed in 2000s, include improved maintenance and repair technologies, reuse, refurbishment and recycling. “Pro-active strategies”, applicable to f new generations of wind turbines, include wind turbine blades with thermoplastic and recyclable thermoset composite matrices, as well as wood, bamboo and natural fiber based composites.

wind energy | wind turbine blades | recycling

1. Introduction

The development of wind energy is an important element of the strategy to limit the global warming. A large expansion of the wind energy is expected in next decades. At the same time, a significant proportion of the installed wind turbines, the generation installed in 2000s, will come to the end of their lifetime between 2020 and 2030. Many parts of wind turbines can be recycled, however, this is seldom the case for the composite wind blades. Thus, the end-of-life management of wind turbine blades is an important problem.

Various scenarios of end-of-life management of wind turbine blades are considered now. “Reactive” strategies, designed to deal with ageing turbines, installed in 2000s, include, amoong others, improved maintenance and repair technologies, reuse, refurbishment and recycling. “Pro-active strategies” seek to ensure recyclability of new generations of wind turbines. They include wind turbine blades with thermoplastic and recyclable thermoset composite matrices, as well as wood, bamboo and natural fiber based composites.

One of the approaches is to postpone the problem, by extending the durability of the blades.The extension of planned lifetime can be based on understanding and preventing specific degradation mechanisms, using stronger and tougher materials, reduced loading, or, in some cases, optimal maintenance strategy. In order to prevent the surface erosion, new engineered coating materials are developed. The use of lighter materials (for instance, carbon fibers versus glass fibers) allows reducing the blade weight, and, thus, ensure lower weight loads on the blades. For the erosion protection, the load reducing strategy can be realized as so-called erosion safe control.

To increase the service time of already installed blades, maintenance and repair are improved. This includes the health monitoring, damage reporting and identification (using the visual inspection, observing the material property changes or non-destructive inspection techniques, artificial intelligence techniques, drones and robots), improved repair procedures, and quality control.

While the life extension and re-use efforts can delay the end of life of the blades, at some stage, the old blade have to be incinerated or recycled. Different recycling technologies for currently used thermoset composites have been developed, including mechanical recycling, pyrolysis and solvolysis.

2. Sustainable End-of-Life Management of Wind Turbine Blades

The current, commonly accepted scenario of wind turbine blade life is 20 to 25 years of service, followed by incineration and landfill, recycling or reuse. However, according to [1], wind turbines (for instance, with blades from epoxy/glass fiber composites) can function without problems until they turn 50 years old.

In view on the sustainability of technologies, the repair, reuse and refurbishment technologies show some advantages, as compared with recycling. Comparing the different end-of-life technologies, Joeman [2] obtained the climate change parameters: 2.02×10^5 kg CO_2 eq for using the blades for making pavements, 1.69×10^4 kg CO_2 eq for pyrolysis application, 3.12×10^3 kg CO_2 eq for refurbishing, 1000 kg CO_2 eq for landfilling.

According to [3][4], recycling and sustainable incineration of resources “hold limited economic and long-term sustainability benefits compared to the reuse, repair and remanufacturing of components”. According to [5], 71% of turbine emission comes from raw materials, 6% from manufacturing, 12% from operation and maintenance. The additional problem of blade recycling is the problem of handling all types of materials in the blade i.e. thermosets, fibers, PVC, PET, PU and balsa wood, coatings. In view of this, the extension of service time of already manufactured blades can be preferential, as compared to manufacturing new blades from new materials.

Repair and reuse are most mature technologies, among other available decommissioning scenarios. In [6], technology readiness levels of different technologies are listed, with relatively low TRL 3 for self-healing polymers, TRL 4 for reversible cross-linking of thermosets, TRL 6 for thermoplastic blades, and high TRL 9 for repair and reuse.

Thus, for now, the strategy of maintenance, repair, reuse and refurbishment has a number of advantages over other approaches (recycling, or new materials, or, on the other side, incineration) (which are in fact still not there). This means that the maintenance, repair and refurbishment technologies should be further developed, to reduce costs, and increase efficiency. This will provide an intermediate solution for coming years, until the new recycling technologies, and, on the other side, new generation of wind turbine blade materials come on the market.

Many ideas of new generation of wind turbine blade materials were successfully tested, in laboratory, and in some cases in field. The rather common feature of these next generation solutions is that they in many cases can be well used for small or even medium size wind turbine blades, but their application for large wind turbines is still constrained, either due to inferior properties, or due to technological challenges. The bio-based composites in wind energy, e.g., natural fiber composites, wood based and bamboo composites, have been tested for small and medium blades, but still did not find application for large blades, due to the inferior mechanical properties of these materials, which are sufficiently lowed than the requirements toward the large wind blades. Sometimes, different performance criteria of the sustainability of wind turbine blade materials are considered separately, like recyclability, easy defect healing, durability, manufacturing from widely available and easily growing natural resources, and also environmental aspects of manufacturing. The materials development for wind turbine blades should include the aspects of sustainability, recyclability, improved lifetime, health monitoring, and maintenance easiness (reparability, health control, etc.).

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References

1. Report “Driftsomkostninger for Ældre Vindmøller” for Energistyrelsen, EMD International A/S (Principal consultant Per Nielsen). 2019. Available online: (accessed on 21 February 2021).
2. Joeman, I. Alternatives on Afterlife Use of Amortized Wind Turbine Blades in the Netherlands. Master’s Thesis, University of Twente, Twente, The Netherlands, 2018/2019. Available online: (accessed on 25 February 2021).
3. Martin, C. Wind Turbine Blades Can’t Be Recycled, so They’re Piling up in Landfills. Bloomberg, 5.2.2020. Available online: (accessed on 5 February 2020).
4. Jensen, P.D.; Purnell, P.; Velenturf, A.P.M. Highlighting the need to embed circular economy in low carbon infrastructure decommissioning: The case of offshore wind, Sustainable Production and Consumption. ScienceDirect 2020, 24, 266–280.
5. A Clean Energy Solution—From Cradle to Grave, Environmental Product Declaration SG 8.0-167 DD 2019; Siemens Gamesa: Zamudio, Spain, 2019.
6. Ierides, M.; Reiland, J. Wind Turbine Blade Circularity. Technologies and Practices Around the Value Chain, Bax & Company. Available online: (accessed on 25 February 2021).