# Chapter 8
# OWT Drivetrain & Gearbox Simulation and Testing

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**Abstract** As wind turbines continue to grow in size and offshore installations become more and more attractive for investors, the design of reliable drivetrains and gearboxes is becoming very critical. One key element is represented by the challenging environmental conditions, which are significantly different and harsher than those experienced by onshore machines. Additionally, a deeper understanding of the operational loads and the effects of combined aero—and hydrodynamic forces on the drivetrain is essential to ensure the wind turbines can be guaranteed for the expected lifetime. These problems result in increased research efforts towards improving the capabilities and the use of simulation tools to better understand the complex drivetrain dynamic behavior. In parallel, advances in experimental techniques are also sought, as a way of deriving reliable information for model verification and validation, and to get a deeper insight in the structure operational response.

## 8.1 Simulation and Testing in Drivetrain and Gearbox Design

The drivetrain and the gearbox in particular continue to play a key role in the wind turbine industry. According to a report published online by OffshoreWIND.biz (2014), the global gearbox market increased from approximately $1.9 billion in 2006 to $4.0 in 2013, thanks in particular to the significant increase in installed power worldwide. However, direct-drive solutions are attracting more and more the interest of the manufacturers and it is expected that the market share of the two solutions (displayed in Fig. 8.1) will soon be balanced.

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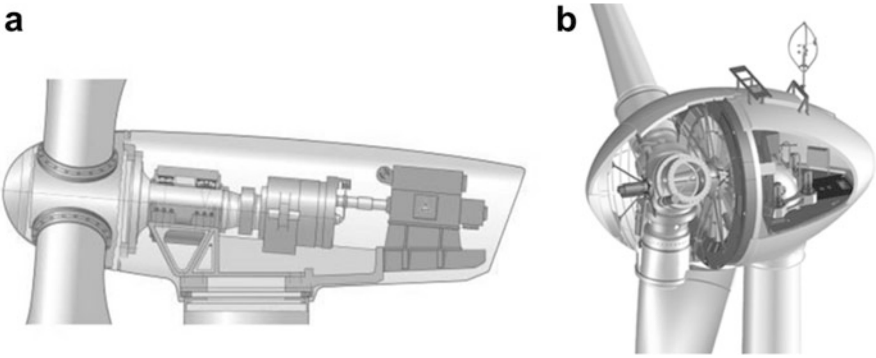


**Fig. 8.1** Typical turbine driveline configurations. (**a**) Gearbox and (**b**) Direct-drive generator

Gearboxes typically have the advantage of requiring smaller initial investments, but because of the number of rotating parts, gear pairs and bearings, reliability is typically an issue. On the other hand, direct-drive machines require a bigger investment related to the development and construction of big permanent magnet generators but have typically lower operation and maintenance costs. To guarantee the effectiveness and competitiveness of the gearbox solution, significant improvements in the design phase are required to better understand the mechanisms leading to gearbox failures. This can only be achieved by developing more accurate, reliable and efficient numerical models, able to replicate not only the global load transfer paths across the driveline but also the local load transfer mechanisms.

More advanced design tools are not only motivated by the call for reliability, but also by other technological drivers which makes the role of the drivetrain more and more critical. As extensively discussed by Helsen et al. (2012), turbine manufacturers are aiming at developing ever bigger machines, with the objective of maximizing the power produced by each individual machine. This trend, over the past 30 years, is shown in Fig. 8.2: bigger and longer blades installed on higher turbines will give access to higher wind speeds and consequently increase the generated power. However, this also poses critical design challenges. Bigger wind turbines and corresponding bigger blades impose higher loads on the turbine components, and in particular the drivetrains, and these loads cannot be considered quasi-static as in the majority of industrial applications. These loads represent a combination of aerodynamic loads at variable wind speeds, gravitational loads and corresponding bending moments, inertial loads due to acceleration, centrifugal and gyroscopic effects, generator torque loads and loads introduced by control actions such as blade pitching, starting up, emergency braking and yawing. Besides, driveline is also subjected to transient phenomena related to sudden wind gusts or electrical grid malfunctioning which generates heavy loads on all rotating components, and in particular on gears and bearing. These effects contribute to non-torque loading, where vertical, horizontal and axial loads are applied on the gears and bearings. Neglecting these effects in design phase is one of the causes of premature failure of gearboxes components, in particular bearings and gears.

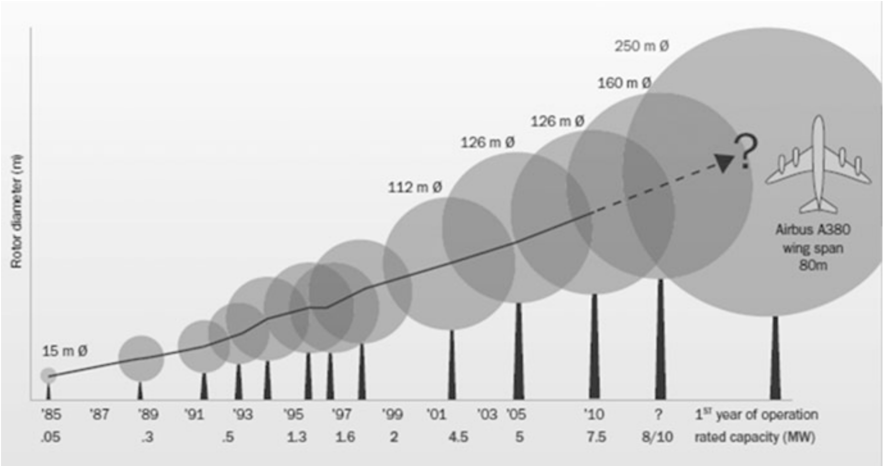


**Fig. 8.2** Wind turbine upscaling trend over the past 30 years (*Source*: FP6 Upwind project, 2011)

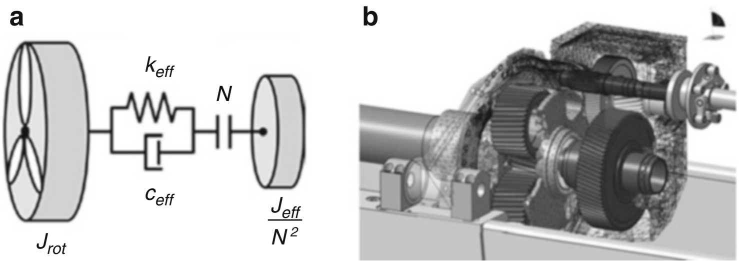


**Fig. 8.3** Modelling approaches for wind turbine gearboxes. (**a**) two DOFs torsional model from Girsang et al. (2013), (**b**) flexible MBS model of the NREL GRC gearbox

Over the past decade, gearbox manufacturers have recognized the limitations related to common design approaches and started integrating more and more numerical tools to validate innovative designs. This paradigm shift represents the foundation of the work by Peeters (2006), where the limitations in traditional design codes for wind turbine design were identified. The work reviews state-of-the-art design tools for wind turbine drivetrain in the early 2000 and introduces a new modelling approach for the simulation of more detailed drivetrain loads relying on the flexible Multibody Simulation (MBS) approach. Two of the discussed modelling approaches, going from two to thousands of degrees of freedom, are shown in Fig. 8.3. The work focused on the importance of modelling the internal dynamics in the gearbox and the complex interaction between the different subcomponents to be able to correctly estimate the operational loads and consequently include this information in the design phase.

The conclusion of Peeters (2006) paved the way for further developments and optimization in the modelling strategies of gearboxes. In the work of Helsen (2012) efficient simulation strategies have been investigated to understand the interaction of the turbine transients with the dynamic excitation within the drivetrain originating from the meshing gears and the full drivetrain structural behavior. The importance of modelling dynamic flexibility of internal gearbox components such as the ring wheel and the planet carrier(s) has also been investigated. Advanced model order reduction techniques based on static mode switching (Tamarozzi et al. 2013) have been applied to accurately simulate a 3D gear contact problem. The results show that the method is able to keep the same level of accuracy of fully non-linear simulation models while drastically reducing the computational resources. Finally, the recent work of Vanhollebeke (2015) demonstrated the possibility to use very accurate flexible MBS models of gearbox and to integrate them in the design phase not only to accurately predict loads but also to efficiently analyze possible NVH problems such as tonalities and vibrations.

Within the MAREWINT project, specific activities were conducted to follow up on these findings and complement the existing work with focus on two specific aspects. Chapter 9 focuses on a review of advanced modelling techniques for bearing and the optimal integration of these models in a flexible multibody simulation environment. In Chap. 10, recent advances on the experimental characterization of gearboxes in operations are presented. Being able to identify an operational model of the gearbox under different loading conditions will provide valuable inputs for validation of global gearbox models and verification of design assumptions.



## References

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