Chapter 1
Introduction

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Abstract The current chapter provides an overview of the offshore wind industry, followed by an introduction to the MARE-WINT project. We discuss the important role that MARE-WINT has fulfilled in reducing the cost of offshore wind energy, by improving the reliability, and operation and maintenance strategies of various wind turbine components. Lastly, we present an overview of the current book for the readers.

1.1 The Emergent Offshore Wind Industry

Wind is one of the most plentiful and widely available natural resources available on our planet. For centuries, mankind has harvested the power of the wind for applications such as maritime and agriculture. Most of the world was explored on the back of wind-powered ships, and it was truly wind that made globalisation and exploration possible.

With society becoming increasingly mindful of the impacts of fossil fuels, renewable energy is on the rise, and the harvesting of wind to generate electricity is becoming increasingly common. To enable this to happen, wind turbines have been installed all over the globe. A vast majority of these wind turbines have been installed on land and are referred to as onshore wind turbines. Statistics by the Global Wind Energy Council (GWEC) indicate that only around 3 % of global electricity is currently generated by wind power—but this number is on the rise.

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The International Energy Agency (IEA) expects that by the year 2035, 25 % of the electricity generation will be fulfilled by renewable sources, and that wind energy will have a major role to play.

1.1.1 The Benefits of Wind Energy

The popularity of wind energy arises from the simple fact that it is, by and large, cost effective, environmentally friendly and socially popular amongst a majority of the populace. A common method of assessing the cost-effectiveness of an energy source is through a parameter called Levelized Cost of Energy (LCOE), which is essentially a ratio between two parameters: the *total lifetime costs* and the *total electricity produced over the lifetime*. Siemens (2014) calculated the LCOE of various electricity generation sources to be as follows:

As Table 1.1 shows, the LCOE of onshore wind is reasonably close to the LCOE of commonly used fossil fuels. However, the LCOE alone does not often provide the complete picture.

A more comprehensive measure, as provided by Siemens (2014) is the so-called Society's Cost of Energy (SCOE). The SCOE takes into consideration further factors such as number of jobs created by energy source, subsidies, transmission costs, variability costs, geopolitical risk impact, and environmental impact. The predicted SCOE in the year 2025 for various electricity generation sources is shown in Table 1.2.

As shown in Table 1.2, it is expected that onshore and offshore wind will be the two most viable sources of energy in the near future. In fact, this phenomenon is already manifesting—statistics indicate the benefits from wind energy to be

Table 1.1 LCOE in 2013 for various electricity generation sources

Source of electricity generation	LCOE (€/MWh)
Nuclear	79
Coal	63
Gas	60
Photovoltaics	145
Onshore wind	81
Offshore wind	140

Source: Siemens (2014)

Table 1.2 SCOE in 2025 for various electricity generation sources

Source of electricity generation	SCOE (€/MWh)
Nuclear	107
Coal	110
Gas	89
Photovoltaics	78
Onshore wind	60
Offshore wind	61

Source: Siemens (2014)

significant. As an example of the social benefits of wind energy, GWEC estimates that more than 600,000 people are employed by the wind industry—a number that is likely to rise to more than 2,000,000 by 2030. In terms of a positive environmental impact, wind energy helped to avoid more than 608 million tonnes of carbon dioxide emissions in 2014 alone. GWEC also estimate that wind farms generate between 17 and 39 times more power than they consume—compared to 16 times for nuclear and 11 times for coal plants (GWEC 2016).

1.1.2 The Challenges of Going Offshore

The continued increase in wind energy is not without its challenges. Offshore wind, in particular, still has some way to go before it can meet the LCOE and SCOE cost expectations. This raises the question—why go offshore at all?

The growth of offshore wind is primarily due to better, more consistent wind resource available on open seas. Combined with limited land space, and the fact that onshore turbines may be less socially acceptable, this makes offshore wind very appealing.

On the other hand, going offshore presents novel challenges—currently, there are limitations in deep-water installation technology, and the harsher environment is not ideal for the reliability, maintainability and availability of offshore wind turbines. Furthermore, offshore wind farms (OWFs) need to be situated in locations where simultaneously, the wind resource *and* the transmission-to-shore options are optimum. Often times, these locations may be in conflict with national, regional or international marine spatial plans, and other sectors such as fisheries and shipping may take precedence in these areas.

There is, thus, a clear need to improve the viability and feasibility of OWFs, and to make offshore turbines closely competitive to their onshore counterparts—and indeed other sources of energy. To fulfil this gap, organizations like the European Commission have encouraged and funded research projects such as MARE-WINT.

1.2 An Introduction to the MARE-WINT Project

The aim of the MARE-WINT (new MAterials & REliability in offshore WInd Turbine Technology) project was to reduce cost of energy, and increase the energy output, by improving reliability of wind turbines and their components and optimizing operation and maintenance (O&M) strategies. Thus, the project contributed towards making wind energy more competitive. The outcomes of the project are particularly evident and relevant for the offshore sector, where O&M represents a high percentage of total costs.

An offshore wind turbine (OWT) is a complex energy conversion fluid flow machine with coupled hydro-aero-mechanical issues. To design, build, and operate a reliable OWT, knowledge from disciplines like mechanical engineering, material science, metrology, fluid mechanics, condition monitoring, and computer simulation needs to be combined. The MARE-WINT network bought together specific partners' capabilities and know-how to realize tailored training trajectories, focusing on an increased reliability OWT design.

MARE-WINT achieved the overall aim by providing training in the context of doctoral programmes for 15 researchers, in multi-disciplinary areas related to future generations of Offshore Wind Turbines (OWT). An emphasis was placed on issues that may have a major impact on the mechanical loading of OWT and which were not sufficiently addressed at the initiation of the project. One of the strengths of MARE-WINT has been the validation of various numerical, analytical and empirical models through experimental data. This has allowed novel concepts such as floating 10 MW wind turbines to be thoroughly investigated, to better prepare the industry for the challenges of tomorrow.

1.3 An Overview of the Current Research

To get a better insight of the outstanding work done by the fellows in the MARE-WINT project—as presented in this book—it is firstly important to understand the components, design process and operation of a typical wind turbine.

1.3.1 The Components of a Wind Turbine

Wind turbines are aero-mechanical devices that convert the rotational movement of a rotor into electrical energy. In order for wind turbines to function, there needs to be wind flowing past them. Wind on Earth is created as a result of the uneven heating of our atmosphere, the irregularities of the Earth's surface, and the actual rotation of our plant. As wind flows past a turbine, it generates a lifting force on the blades of a wind turbine—which are connected to a rotor. The lifting force on the blades creates a rotational movement on the rotor. This rotational movement is transferred, via a shaft and gearbox, to a generator where it is converted into electrical energy. The components of a turbine are shown in Fig. 1.1.

1.3.2 Designing a Wind Turbine

Within the MARE-WINT project, several researchers worked in the context of the 10 MW reference turbine developed by the Technical University of Denmark (DTU), and described by Bak et al. (2013); the parameters are shown in Table 1.3.

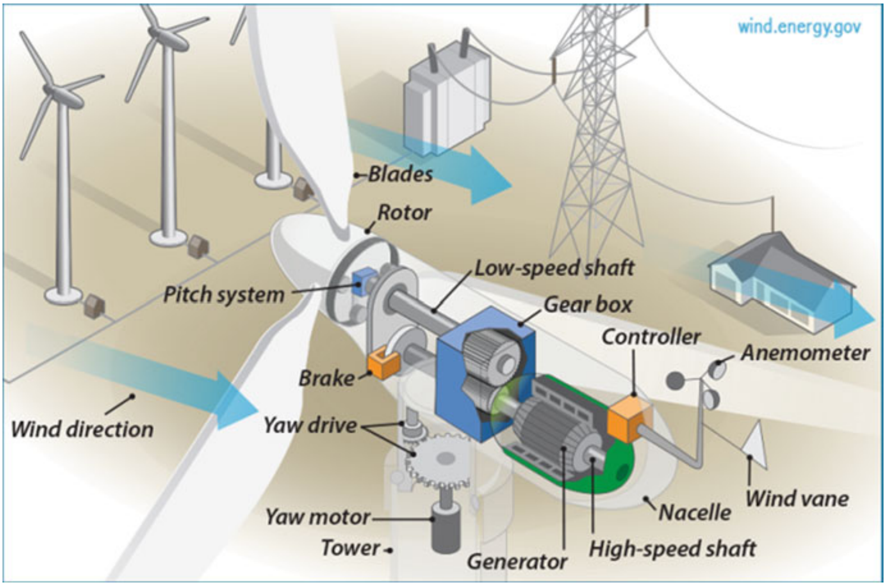

Fig. 1.1 Wind turbine components. *Source*: wind.energy.gov; copyright: public domain

Table 1.3 Properties of the 10 MW DTU reference wind turbine

Parameter	Value
Rating	10 MW
Rotor orientation, configuration	Upwind, three blades
Control	Variable speed, collective pitch
Drivetrain	Medium speed, multiple stage gearbox
Rotor, hub diameter	178.3 m, 5.6 m
Cut-in, rated, cut-out wind speed	4 m/s, 11.4 m/s, 25 m/s
Cut-in, rated rotor speed	6 RPM, 9.6 RPM
Rated tip speed	90 m/s
Overhang, shaft tilt, pre-cone	7.07 m, 5°, 2.5°
Pre-bend	3 m
Rotor mass	229 tons (each blade ∼41 tons)
Nacelle mass	446 tons
Tower mass	605 tons

Source: Bak et al. (2013)

To design and develop this 10 MW reference turbine, the Bak et al. (2013) applied the method shown in Fig. 1.2.

Figure 1.2 has a heavy emphasis on aerodynamics and structural mechanic and is, in fact, only a simplified version of a much more sophisticated process. Typically, as shown in Fig. 1.2, the starting point for a wind turbine concept is the design of the blades. The size (primarily, the length) of the blades directly determines the capacity

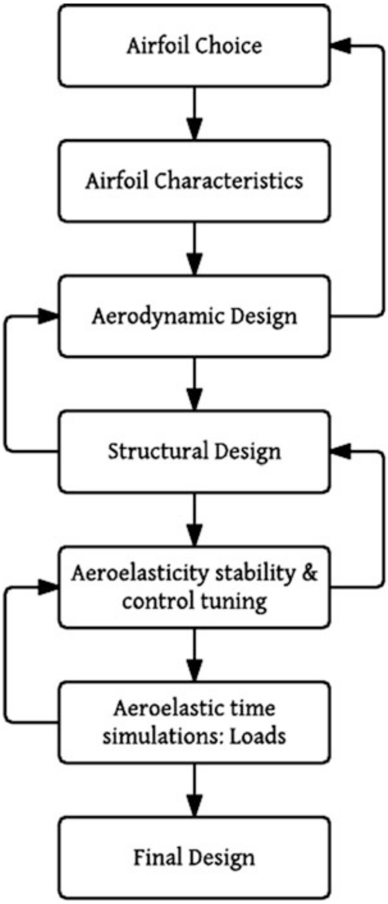

Fig. 1.2 Method for developing the 10 MW reference wind turbine. Adapted from Bak et al. (2013)

of the turbine. As a rule of thumb, the larger the diameter, the greater the power output of the turbine. Of course, principals of aerodynamics govern the efficiency of the wind turbine. On a very basic level, the Betz law means that theoretically only around 59.3 % (16/27) of the kinetic energy from wind can actually be captured—no matter how large the rotor size is; furthermore, being a mechanical device, there are further inefficiencies in the system, which means that only around 75–80 % of the 59.3 % theoretical cap is actually achieved. In order to make wind turbines more reliable and efficient, these inefficiencies need to be minimized as much as possible. Therefore, the design of blades is crucial. Blades must be aerodynamically efficient, whilst at the same time being structurally sound enough to bear all the mechanical and aerodynamic loads. Balancing the aerodynamic and structural parameters is becoming increasingly challenging as wind turbines get larger and more sophisticated.

The blades are connected to a rotor, which in turn is connected to a shaft, which goes through a gearbox into the generator. The shaft and gearbox must be able to tolerate the mechanical loads in an often harsh environment, and be able to transmit the rotational movement as efficiently as possible. If the drivetrain and gearbox are unable to handle the loads from the blade and rotor, the blades design may have to be changed; alternatively, the gearbox and drivetrain would be updated. The research in this area, too, is critical as offshore turbines get more complex.

The blade and the nacelle (housing the gearbox and generator, amongst other components) assembly must be supported on an adequate tower structure, which in turn needs to be mounted or tethered on the sea-bed through an appropriate sub-structure. Depending on the design requirements and factors such as the turbine location, optimizing the tower and sub-structure can be a substantial task. The tower and sub-structure must not only cope with aerodynamic and mechanical loading (particularly from the blades, rotor and nacelle), but also bear its own load and various hydrodynamic loads. As with the research conducted for the blades and the gearbox, optimizing the tower and support structure for larger, more complex turbines is a unique challenge.

Once all the components are in place and assembled, the overall reliability of the turbine and all its sub-systems must be assessed. Furthermore, maintenance strategies must be optimized in order to reduce the costs associated with offshore wind. If it is unfeasible to maintain a wind farm in a cost effective manner, the design or maintenance strategy may have to be adapted.

To ensure that a turbine is reliable and efficient, it is also important to analyse the complete system. This is generally done using combined fluid and structural analysis methods, to ensure that the components complement each other, and are able to tolerate design loads without failures occurring.

A wind turbine on its own is often not the end goal—it needs to be integrated into a wind farm. In order to do so, one must analyse the aerodynamic effects of wake turbulence from each individual turbine over the entire proposed wind farm area. This helps to determine the efficiency of various turbines in different layouts. The layout of a wind farm is not only driven by aerodynamic factors; factors such as seabed conditions, grid connection locations, hydrography and bathymetry must also be taken into account. Furthermore, wind resource in an area must be considered. Equally important is the consideration of potential 'conflict' or 'overlap' areas—which may be reserved for marine, environmental, or other purposes. The layout of any wind farm can also have an impact on the navigational safety of passing vessels; in turn, vessel accidents in the area may damage wind turbines, or cause a wind farm shutdown, leading to reduced reliability. Wind turbine towers may have to be designed to be 'collision-friendly' to ships (BSH 2015). A potential conflict with other marine and maritime activities may cause a wind farm application to be denied, or at the very least, the layout may have to be changed.

Wind turbines are designed to last around 25 years. Once their lifetime has been fulfilled, the turbines need to be decommissioned. This is a fairly novel research area, as most offshore turbines are *just* now entering their end-of-life cycle. Despite this, the decommissioning is an important phase to consider when assessing LCOE, as it can have a significant impact on the parameter. It may even be the case that a wind farm is approved or denied permission based on its decommissioning plan.

1.3.3 MARE-WINT's Contribution to the Offshore Wind Industry

In the MARE-WINT project, the focus was not solely on the *design* of a wind turbine; rather, the fellows also focused on developing tools to analyse and improve the reliability and efficiency of various wind turbine components. The best way to highlight the contributions of the MARE-WINT project is by summarizing the content of the present book, which more or less covers the topic areas identified in Sect. 1.3.2:

- Part I of this book focuses on blade design, and tools to improve analysis and reliability of wind turbine blades. This research ranges from damage sensing to the analysis of bend-twist coupling of blades—and even a study into rod-vortex generators to minimize aerodynamic noise on the blade. Part I also describes the 'Smart-Blade' strategy used in the current work.
- Part II focuses on analysing and improving the reliability of these components. The research described in this part of the book can allow turbine engineers to assess the adequacy of the drivetrain and gearbox sub-systems.
- Part III presents tools that can be used to study, analyse and improve the reliability and design of the tower and substructure. Researchers performed a thorough fluid–structure interaction analysis of different wind turbine concepts—floating, horizontal axis, and vertical axis, and determined the feasibility and viability of each, compared to the others. Researchers also conducted numerical and experimental studies focusing on hydrodynamic loads on various substructures and towers. Lastly, a tool for structural health monitoring, to provide an improved method of assessing turbine tower damage is also presented.
- Part IV discusses tools, methods strategies which can be used to analyse and improve reliability and preventive maintenance of offshore wind turbines.
- Part V of the current book presents novel research in this area of complete offshore wind turbine analysis. It describes relevant tools and models to assess the fluid–structure interactions in a complex system like an offshore turbine.
- Part VI covers the crucial area of wind farm design. Topics including aerodynamic simulations over wind farms, maritime risk assessment are covered. The EERA-DTOC tool for designing wind farm clusters is also presented.
- Part VII of this book covers original decommissioning tools and strategies, both from an industry and research perspective.

Several topics are not explicitly covered in this book, as they have been sufficiently addressed in other published works. The spatial planning and approval of wind farms, for instance, has been the focus of the SEANERGY project (EWEA et al. 2012). Similarly, the environmental impacts of wind farms have been covered by Koeller et al. (2006). The installation process of OWFs is also not explicitly covered in this current work, although it is briefly discussed in Chap. 22, in the context of the decommissioning phase of offshore turbines. Aside from these aforementioned areas, the book comprehensively covers all topics from design to decommissioning of OWFs.

1.3.4 Contributions from External Authors

The majority of the content in this book has been has been generated from original research conducted within the MARE-WINT project. Some research topics, however, were not explicitly researched within the project; instead, subject matter experts were invited to speak to the fellows during various training workshops. Some of these experts were also invited to provide specific chapters for the book.

- Gregor Giebel and Charlotte Bay Hasager provided Chap. 19.
- Johan Finsteen Gjødvad and Morten Dallov Ibsen authored Chap. 22.
- Justine Beauson and Povl Brøndsted presented Chap. 23.

This book has been authored for everyone interested in advanced topics related to offshore wind energy. It provides a unique perspective—both academic and industrial—on novel research topics that will shape the future of the offshore wind industry. On behalf of all the editors and authors, we wish you a very pleasant and insightful reading!

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