Michael Durstewitz
Bernhard Lange *Eds.*

Sea – Wind – Power

Research at the first German offshore wind farm Alpha Ventus

Springer

Sea – Wind – Power

Michael Durstewitz
Bernhard Lange
(Eds.)

Sea – Wind – Power

Research at the first German
Offshore Wind Farm *Alpha Ventus*

Springer

Editors
Michael Durstewitz
Fraunhofer-Institut für Windenergie
und Energiesystemtechnik IWES
Kassel, Germany

Bernhard Lange
Fraunhofer-Institut für Windenergie
und Energiesystemtechnik IWES
Bremerhaven, Germany

Translation:
Federal Ministry for Economic Affairs and Energy (Foreword by the Federal Minister)
Alistair A. Tarwid for LUND Languages (except chapter 11)

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

RAVE
RESEARCH AT ALPHA VENTUS

Fraunhofer
IWES

ISBN 978-3-662-53178-5 ISBN 978-3-662-53179-2 (eBook)
DOI 10.1007/978-3-662-53179-2

Library of Congress Control Number: 2016957413

Editor: Stefanie Wolf
Cover illustration: DOTI/Matthias Ibeler

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer-Verlag GmbH Germany
The registered company adress is: Heidelberger Platz 3, 14197 Berlin, Germany

Foreword by the German Federal Minister for Economic Affairs and Energy

The use of both onshore and offshore wind energy is a key element in Germany's energy transition. Today, onshore wind energy is already the primary source of renewable energy in electricity generation in Germany. The increased expansion of offshore wind turbines still offers a great deal of potential. However, it also requires a lot of innovative solutions to be developed in the areas of construction and operation.

The research undertaken at the first German offshore wind farm Alpha Ventus has played a crucial part in helping to build up knowledge and expertise in what is still a very young sector in energy generation in Germany. It is particularly pleasing that the various research projects could be coordinated with one another so well, and that it has been possible to combine the different interests of researchers, facility operators, and plant manufacturers, whilst also ensuring that expansion work is environmentally sound. The Alpha Ventus wind farm is a pioneering venture which – together with the research initiative 'Research at Alpha Ventus – RAVE' – has laid the foundations for German projects in the area of offshore wind energy. The results of the research are outstanding – something which is also reflected in the level of international interest that has been attracted.

There is, of course, still a great deal of research yet to be carried out on developing the use of wind energy in Germany. We will only be able to use the potential that exists in this field if we continue to reduce the costs of electricity from wind energy and continue to raise grid security. Doing so will enable Germany's wind sector to stay competitive in the long term.

Given this background, the primary aim of the research funding provided by the Federal Ministry for Economic Affairs and Energy is to reduce both the investment and the operating costs for wind-powered installations. The state-of-the-art in German wind-power technology is impressive – with German industry setting international standards based on high-capability wind-powered installations 'Made in Germany'.

When it comes to the expansion of wind power into the future, it will be crucial to ensure that the electricity generated by wind turbines can be reliably integrated into the public grids. Indeed this is one of the priorities that the Federal Ministry for Economic Affairs and Energy has set in the area of energy research. Further research is needed in areas such as optimising

the grid connection of offshore wind farms, load and generation management, wind-energy-specific aspects of storage, and improvements in wind forecasts.

German companies, universities, and research establishments are among world leaders in wind energy thanks to the innovations that are being generated in this field. Research activities are being supported by German manufacturers and service providers, who are developing solutions designed to meet the specific requirements of foreign markets. The Federal Ministry for Economic Affairs and Energy is providing funding for these activities with the aim of ensuring the highest possible value generation in wind energy in Germany and, through this, of making the German wind industry internationally competitive.

I am delighted that an essential overview of the many different research projects being funded by the Federal Government as part of the Energy Research Programme now appears in book form. I wish you interesting reading and hope that this publication will serve as a source of inspiration to you.

Sincerely yours,

Sigmar Gabriel
Federal Minister for Economic Affairs and Energy

Foreword by the Chair of the Offshore Wind Energy Foundation

The construction of the Alpha Ventus test field played a significant role in the development of offshore wind energy in Germany. Within five years of it being commissioned in April 2010 there were wind farms in the German North and Baltic Seas with an output of 3,294 megawatts connected to the grid. And based on the investment decisions and business planning already made, the output will have more than doubled by 2020 – while optimistic predictions reckon that the government-set upper limit of 7.7 gigawatts will be fully utilised. This breakthrough of this new technology, which had no easy task in overcoming many teething troubles, would not have been possible without the extensive research projects and their findings that were part of the RAVE research initiative.

Over 50 universities, research institutions and businesses have been involved in numerous individual projects dealing with the solution of problems that would improve offshore wind turbine technology, making it safer and more profitable while also optimising its compatibility with the marine environment. The entire German offshore wind industry has profited from this.

The foundation would therefore like to thank all the scientists who have been involved in this national offshore wind research project and who have thus helped a new technology to make its breakthrough.

On behalf of this research community the foundation would especially like to thank Project Management Jülich (PtJ) and the Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), who supported and coordinated the individual scientific works, and aggregated all the results.

The RAVE research network has made a great contribution to the development of offshore wind energy in Germany.

Jörg Kuhbier
Chairman, Offshore Wind Energy Foundation

CSI Test Field, CSI Offshore

Publisher's Foreword

RAVE: 1) a frolicking crowd, a dancing mass of people, a swarm 2) abbreviation of Research at Alpha Ventus. So ambiguous and yet so applicable, because the installation and investigation of Germany's first offshore wind farm, Alpha Ventus, also proved to be a ride over the North Sea, for everyone involved.

The start signal for RAVE was given just eight years ago and it is already hard to visualise what it was like back then. Nobody had ever had any experience of erecting wind turbines so far out at sea, over 40 kilometres from the nearest piece of dry land. Nor did anyone have any experience of building wind turbine foundations in water 30 metres deep. The foreseen five-megawatt wind turbine generation was also new and had never been tested out at sea. But we are in a very different position today; nobody asks the question "Is that at all possible?" any more. Five-megawatt turbines are now old hat. Today around 800 offshore wind turbines are operating in German waters, and over 3,200 in Europe. That is also thanks to Alpha Ventus and RAVE.

Both of them are success stories. With around 4,500 full load hours of wind power a year, Alpha Ventus is very impressive. This is especially so compared with other European offshore wind farms – even though Alpha Ventus is a test field. The experiences made and the operating results of Alpha Ventus have significantly contributed to building trust in the technology, which is a prerequisite for further expansion. And this indeed came to pass; in 2015 there was a record 2,282 megawatts of new offshore installations in Germany. There are now offshore wind farms with a total of around 3,300 megawatts on grid. The government goal of achieving its short-range target of 6,500 megawatts of offshore wind power by 2020 appears feasible. Based on current information, around 80 % of the projects planned to date have the financing in place.

RAVE is also a success story. Never in the history of wind power has there been such a large coordinated research initiative, in which the industry and research institutions have acted so in concert. And with success, because within just a few years not only have the manufacturers involved been able to develop their wind turbines further, but based on the research findings they have also been able to develop new guidelines that are now applied across the entire industry. Last but not least, the project has also provided new fundamental knowledge, ranging from the behaviour of porpoises to loads caused by breaking waves. Within just a few years, German offshore wind energy research has made it to the top of the international league – as proven by the many publications and conference contributions.

RAVE has been a joint effort. Despite, or perhaps because of, all the obstacles that had to be overcome. "We were all bitten by the offshore bug." Us, all the researchers involved in Alpha Ventus, Germany's first North Sea wind farm. We are proud that this test field came to fruition – and that we scientists were able to research in the field. Also very important was the financial support that first enabled this research work, for which we must thank the Project Management Jülich PtJ and the Federal Ministry of Economics and Energy. Over 50 universities, research institutes and businesses have been involved in the RAVE research. Their results help to further develop offshore wind energy use.

An incredible amount has been achieved in the past ten years. Our knowledge has increased enormously. But as we all know, miracles take a bit longer, and that is something we should bear in mind when all that is discussed nowadays is how quickly we can expand offshore wind power and how quickly the costs can be reduced. Despite the massive advances made, the offshore wind industry is still a very young industry, which still needs a long time – which it must also be allowed – in order to complete its knowledge, optimise its technology and gather operational experience. Offshore wind farms are built for an operational life of at least 20 years and even the first German offshore wind farm, Alpha Ventus, is not even half way there yet.

Research can make a contribution, and wants to. The long-term behaviour of materials and components in the harsh offshore conditions has to be investigated and understood. Deeper knowledge enables innovations that can reduce the cost of power generated offshore. New approaches in planning, production, construction and operation of offshore wind farms have to be conceived, developed and tested. In ten years' time wind farms will look very different, and also cost less than today.

One last question remains to be asked. Who is this book really aimed at? Everyone interested in offshore wind power, and everyone who wants to understand what research issues had and have to be solved if they are to become reality. In other words, it is for everyone who wants to know more about the work and (interim) results from Germany's first offshore test field. And it is for those who do not want to first study engineering or physics if they are to understand it. This book is an attempt to express the scientific findings of RAVE in a way that is generally understandable. If anyone wishes to have more detailed information we recommend that they read the final reports of the respective research projects, look at the Internet presentations or speak to those involved in the projects.

Offshore wind power in Germany is only just getting started. Research into it continues, and hopefully the success story will also. We researchers want to make our contribution and look forward to doing so.

Foreword to the English edition

After more than half a decade of research involving over 50 universities, research institutes and businesses, Alpha Ventus is the world's most thoroughly investigated offshore wind farm. This translation of the German book "Meer – Wind – Strom" will also give a wider international readership the opportunity to share in the results of the RAVE research project.

Michael Durstewitz

Dr. Bernhard Lange

Credits

We would like to thank

- All the authors for their effort and involvement, for their patience in explaining everything, their work in correcting, for their courage and willingness to tread new paths with this book.
- The Springer editorial office, in the person of Kerstin Hoffmann, for her understanding and willingness to make new production times possible time and again.
- The whole team at Fraunhofer IWES, especially Uta Werner and Evgenia Gostrer for the graphics and prompt image processing, Susann Spriestersbach for coordination and help, and Lena Schuldt for her extraordinarily great, committed and all-round help during the whole production process.
- The Federal Ministry for Economic Affairs and Energy and Project Management Jülich, who made the realisation of this work possible.
- And the many other helpers who supported us during the production and who contributed to the publication of "Sea – Wind – Power".

Michael Durstewitz, Bernhard Lange, Björn Johnsen
Kassel, Bremerhaven, Hannover in February 2016

Contents

III Turbine Technology and Monitoring

V Environment and Ecology

List of Authors

Dr. Matthias Baeßler
Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin
matthias.baessler@bam.de

Anika Beiersdorf
formerly Federal Maritime and Hydrographic Agency (BSH)
Hamburg Port Authority (HPA)
Neuer Wandrahm 4
20457 Hamburg
anika.beiersdorf@hpa.hamburg.de

Volker Berkhout
Fraunhofer IWES
Königstor 59
34119 Kassel
volker.berkhout@iwes.fraunhofer.de

Dr. Michael Benesch
Rützenhagen 1
23795 Negernbötel
mben@gmx.de

Axel Binder
Federal Maritime and Hydrographic Agency (BSH)
Bernhard-Nocht-Straße 78
20359 Hamburg
axel.binder@bsh.de

Kristin Blasche
formerly Federal Maritime and Hydrographic Agency (BSH)
Hamburg
Kristin.blasche@gmail.com

Dr. Maria Boethling
Federal Maritime and Hydrographic Agency (BSH)
Bernhard-Nocht-Straße 78
20359 Hamburg
maria.boethling@bsh.de

Dr. Lüder von Bremen
ForWind – University of Oldenburg
Ammerländer Heerstraße 136
26129 Oldenburg
lueder.von.bremen@forwind.de

Dr. Beatriz Cañadillas
UL International GmbH
Ebertstraße 96
26382 Wilhelmshaven
b.canadillas@dewi.de

Christine Carius
formerly Charité – Universitätsmedizin Berlin
carius@bwl.uni-kiel.de

Dr. Pablo Cuéllar
Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin

Christian Dahlke
formerly Federal Maritime and Hydrographic Agency (BSH)
cd.dahlke@googlemail.com

Prof. Stefan Emeis
Institute of Meteorology and Climate Research
Karlsruhe Institute of Technology
Kreuzeckbahnstraße 19
82467 Garmisch-Partenkirchen
stefan.emeis@kit.edu

Stefan Faulstich
Fraunhofer IWES
Königstor 59
34119 Kassel
stefan.faulstich@iwes.fraunhofer.de

Dr. Richard Foreman
formerly UL International GmbH
Ebertstraße 96
26382 Wilhelmshaven
r.foreman@dewi.de

Dr. Moritz Fricke
Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
m.fricke@isd.uni-hannover.de

Steven Georgi
Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin

Dr. Tanja Grießmann
Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
t.griessmann@isd.uni-hannover.de

Dr. Gerrit Haake
formerly Adwen GmbH
gerrit.haake@gmx.de

Dr. Moritz Häckell
Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
m.haeckell@isd.uni-hannover.de

Berthold Hahn
Fraunhofer IWES
Königstor 59
34119 Kassel
berthold.hahn@iwes.fraunhofer.de

Wilhelm Heckmann
Offshore Wind Consultants (Aqualis) GmbH
Poststraße 33
20354 Hamburg
wilhelm.heckmann@owcltd.co.uk

Kai Herklotz
Federal Maritime and Hydrographic Agency (BSH)
Bernhard-Nocht-Straße 78
20359 Hamburg
kai.herklotz@bsh.de

Prof. Heiko Hinrichs
University of Applied Sciences Bremerhaven
fk-wind: Institute for Wind Energy
An der Karlstadt 8
27568 Bremerhaven
hhinrichs@hs-bremerhaven.de

Dr. Annette Hofmann
Adwen GmbH
Am Lunedeich 156
27572 Bremerhaven
annette.hofmann@de.adwenoffshore.com

Thole Horstmann
University of Applied Sciences Bremerhaven
fk-wind: Institute for Wind Energy
An der Karlstadt 8
27568 Bremerhaven
thole.horstmann@hs-bremerhaven.de

Prof. Gundula Hübner
Martin Luther University Halle-Wittenberg
Psychology Department
06099 Halle (Saale)
gundula.huebner@psych.uni-halle.de

Christoph Jacob
formerly Charité – Universitätsmedizin Berlin

Björn Johnsen
Windmedia
Querstraße 31a
30519 Hannover
johnsen@windmedia.de

Krassimire Karabeliov
Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin

Dr. Jan Kruse
Senvion GmbH
Überseering 10
22297 Hamburg
jan.kruse@senvion.com

Uta Kühne
University of Applied Sciences Bremerhaven
fk-wind: Institute for Wind Energy
An der Karlstadt 8
27568 Bremerhaven
uta.kuehne@fk-wind.de

Marco Lewandowski
BIBA - Bremer Institut für Produktion und Logistik GmbH
Hochschulring 20
28359 Bremen
lew@biba.uni-bremen.de

Hans-Peter Link
DNV GL
Sommerdeich 14b
25709 Kaiser-Wilhelm-Koog
hans-peter.link@dnvgl.com

Monika Mazur
Fraunhofer IWES
Am Seedeich 45
27572 Bremerhaven
monika.mazur@iwes.fraunhofer.de

Dr. Thomas Neumann
UL International GmbH
Ebertstraße 96
26382 Wilhelmshaven
t.neumann@dewi.de

Dr. Nico Nolte
Federal Maritime and Hydrographic Agency (BSH)
Bernhard-Nocht-Straße 78
20359 Hamburg
nico.nolte@bsh.de

Stephan Oelker
BIBA – Bremer Institut für Produktion und Logistik GmbH
Hochschulring 20
28359 Bremen
oel@biba.uni-bremen.de

Dr. Johannes Pohl
Martin Luther University Halle-Wittenberg
Psychology Department
06099 Halle (Saale)
johannes.pohl@psych.uni-halle.de

Dr. Hermann van Radecke
Fachhochschule Flensburg
Kanzleistraße 91–93
24943 Flensburg
hermann.vanradecke@fh-flensburg.de

Dirk Reinhold
Senvion GmbH
Am Friedrichsbrunnen 2
24782 Büdelsdorf
dirk.reinhold@senvion.com

Prof. Raimund Rolfes
Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
r.rolfes@isd.uni-hannover.de

Jörg Rustemeier
Leibniz Universität Hannover – ForWind
Appelstraße 9A
30167 Hannover
j.rustemeier@isd.uni-hannover.de

Dr. Werner Rücker
Federal Institute for Materials Research and Testing
Unter den Eichen 87
12205 Berlin
werner.ruecker@bam.de

Ingo Schlalos
SWMS Systemtechnik Ingenieurgesellschaft mbH
Donnerschweer Straße 4a
26123 Oldenburg
schlalos@swms.de

Dr. Martin Schultz
formerly Charité – Universitätsmedizin Berlin
Heart and Diabetes Center NRW
Institute for Applied Telemedicine
Georgstraße 11
32545 Bad Oeynhausen
mschultz@hdz-nrw.de

Prof. Henry Seifert
University of Applied Sciences Bremerhaven
fk-wind: Institute for Wind Energy
An der Karlstadt 8
27568 Bremerhaven
hseifert@hs-bremerhaven.de

Sebastian Stock
Fraunhofer IWES
Königstor 59
34119 Kassel
sebastian.stock@iwes.fraunhofer.de

Prof. Klaus-Dieter Thoben
BIBA – Bremer Institut für Produktion und Logistik
GmbH
Hochschulring 20
28359 Bremen
tho@biba.uni-bremen.de

Dr. Arne Wessel
Fraunhofer IWES
Königstor 59
34119 Kassel
arne.wessel@iwes.fraunhofer.de

Construction, Operation, Measurement, Coordination

Metamorphoses of an Offshore Wind Farm

Planning, Construction and Operation of Germany's First Offshore Wind Farm and Test Field Alpha Ventus

Björn Johnsen

M. Durstewitz, B. Lange (Eds.), *Sea – Wind – Power,* DOI 10.1007/978-3-662-53179-2_1

1

Project information: Planning, construction and operation of a 60 MW offshore wind farm 45 kilometres off the island of Borkum for test and research purposes
Project management:
DOTI – Deutsche Offshore-Testfeld- und Infrastruktur-GmbH & Co. KG
Wilfried Hube

1.1 In the Beginning Was the Sea

No experience of offshore wind turbines, not much chance of a profit, uncertain territory, and then off out onto the high seas. The first time anywhere in the world at such a great distance from land, in water depths of 30 metres, and a service life of 20 years. Faced with such an investment prospect any business would usually say "Thanks, but no thanks". Luckily the discussions during the planning, construction and operation of Germany's first offshore test field went much better – and finally the Alpha Ventus wind farm actually became reality under the leadership of Deutsche Offshore-Testfeld und Infrastruktur GmbH & Co. KG. Generally known as DOTI, this is a joint venture by energy suppliers EWE, E.ON and Vattenfall which realised Germany's first offshore project in the North Sea and has been operating it ever since (Fig. 1.1). With 4,500 and more full load hours, Alpha Ventus is unparalleled anywhere in Europe. But first things first.

Peripheral Anecdote (I): Legal commuting between Hamburg, the capital and East Frisia
The start was made in East Frisia. In the autumn of 1999, the owner of a wind farm planning and design office, Ingo de Buhr, visited the Federal Maritime and Hydrographic Agency (BSH) in Hamburg to present his plans for the erection of the "Borkum West" wind farm. It was Germany's first offshore wind farm project. There was not yet a legislative framework for offshore wind farms, nor were there any proper wind measurements. EU-wide the use of an exclusive economic zone beyond the 12-sea-mile limit had only been in force for a few years. BSH lawyer Christian Dahlke created the legal framework for offshore wind farms quite quickly, for example with the "Standards for Environmental Impact Assessments", introduced in 2002. There was resistance from residents of the island of Borkum, but backing and great plans from Berlin. In 2002 the federal government set a target of installing 500 megawatts of offshore wind power by the end of 2006, and "at least two to three thousand megawatts more by 2010". At least three German wind turbine managers considered getting involved in offshore wind power. By the start of the new millennium planning was moving ahead at a pace, but the costs of construction were outstripping the budget. The banks were unwilling to risk the financing, insurers were unwilling to insure, manufacturers still had no offshore experience and, putting it diplomatically, there was a great deal of room for improvement as far as the grid operators' inclination to provide the connection to the grid was concerned. For many of the players it was quite clear that the billion-euro offshore business was too expensive for conventional planning and design offices. Offshore, the standard wind farm size of 40 to 50 turbines quickly exceeded the billion-euro mark. Without the involvement of the major energy suppliers there was no way offshore could succeed – it needed an "icebreaker" to prove that offshore wind energy use does work.
So the planned Borkum West wind farm went through a metamorphosis. The planning and design rights were transferred to a specially established foundation, the "Stiftung der deutschen Wirtschaft zur Nutzung und Erforschung der Windenergie auf See" (Offshore Wind Energy Foundation). In autumn 2005, just before the general election, the federal ministry provided its five million euros of starting capital. The Alpha Ventus test field with twelve turbines built by Adwen (then Areva) and Senvion (then REpower) went into planning.