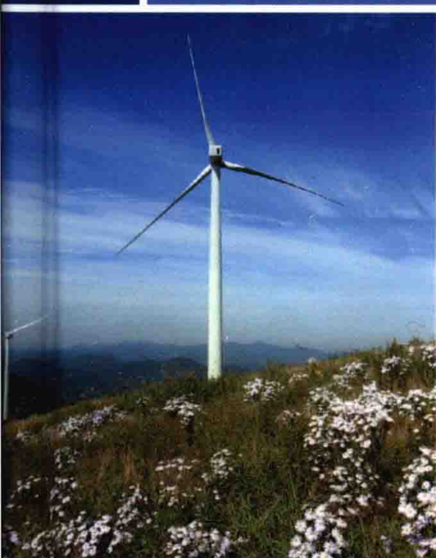
Wind Energy

Theory and Applications



Jayce McCarthy

Wind Energy: Theory and Applications

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Larsen & Keller
www.larsen-keller.com

Wind Energy: Theory and Applications
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ISBN: 978-1-63549-298-9 (Hardback)

Larsen & Keller
Published by Larsen and Keller Education,
5 Penn Plaza,
19th Floor,
New York, NY 10001, USA

Cataloging-in-Publication Data

Wind energy : theory and applications / edited by Jayce McCarthy.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-63549-298-9
1. Wind power. 2. Wind power--Environmental aspects. 3. Wind power--Law and legislation.
4. Renewable energy sources. I. McCarthy, Jayce.

TJ820 .W56 2017
621.45--dc23

Printed and bound in China.

For more information regarding Larsen and Keller Education and its products, please visit the publisher's website www.larsen-keller.com

Wind Energy: Theory and Applications

Preface

This book aims to shed light on some of the unexplored aspects of wind energy. It describes in detail the importance of wind power in the present scenario. Wind power refers to the science and technology of using wind turbines to generate electricity. It is a renewable source of energy and is an alternative for fossil fuels. This textbook is a compilation of chapters that discuss the most vital concepts in the field of wind power. It outlines the processes and applications of the subject in detail. Most of the themes introduced in this book cover fundamental techniques and application of wind energy. Coherent flow of topics, student-friendly language and extensive use of examples make the book an invaluable source of knowledge.

A short introduction to every chapter is written below to provide an overview of the content of the book:

Chapter 1 - Wind power is the power generated by wind with the help of wind turbine technology. It can be used as an alternative for fossil fuel. Wind power is preferred for it is renewable, clean and produces no greenhouse gas. The chapter on wind power offers an insightful focus, keeping in mind the complex subject matter; **Chapter 2 -** The techniques used for the generation of wind powers are wind farms, offshore wind power, high-altitude wind power, windmills and windpumps. Wind farms consist of several individual wind turbines whereas the wind farms constructed on continental shelfs are known as offshore wind power. The aspects elucidated in the text are of vital importance, and provide a better understanding of wind power; **Chapter 3 -** Wind turbine is a device that converts wind into electrical power. They are manufactured in a wide range; the range differs from vertical to horizontal axis types. Some of the aspects discussed within this chapter are wind turbine design, airborne wind turbine, vertical axis wind turbine, floating wind turbine and unconventional wind turbines. This chapter is an overview of the subject matter incorporating all the major aspects of wind turbines; **Chapter 4 -** Wind power can be harnessed using wind turbines to power mechanical vehicles. These vehicles have been dubbed as 'land yachts'. An overview of crafts and vehicles running in the ocean and on land that operate on wind power is provided in this chapter; **Chapter 5 -** The chapter concentrates on two basic laws related to wind power. Bert's law and wind profile power law; Bert's law directs the maximum power that can be extracted by wind. Wind profile power law is the law that forms a relation between the speed of wind at one height, and the same at another. This section serves as a source to understand the major laws related to wind power; **Chapter 6 -** Wind power can be utilized in several ways in the near coming future. Some of the future prospects discussed in the following chapter are wind power forecasting, wind hybrid power systems and wind resource assessment. Wind power forecast provides an estimation of the expected production of one or more wind turbines. Wind power is emerging as a technology; the following chapter will not provide an overview, it will also delve into the topics related to it; **Chapter 7 -** Wind power generates the least global warming as per unit of electrical energy produced. Wind power consumes less land, generates less greenhouse gas and is also renewable. In comparison the effect wind power has to the effect is relatively minor to the effect fossil fuels have to the environment. This section explains to the reader the importance of wind power in contemporary times; **Chapter 8 -** The history of wind power can be traced by the evolution of devices that use this energy. Wind mills, sail ships are important landmarks in human technological history. This chapter provides an overview of the history of wind power and wind power related devices.

Finally, I would like to thank my fellow scholars who gave constructive feedback and my family members who supported me at every step.

Editor

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Introduction to Wind Power

Wind power is the power generated by wind with the help of wind turbine technology. It can be used as an alternative for fossil fuel. Wind power is preferred for it is renewable, clean and produces no greenhouse gas. The chapter on wind power offers an insightful focus, keeping in mind the complex subject matter.

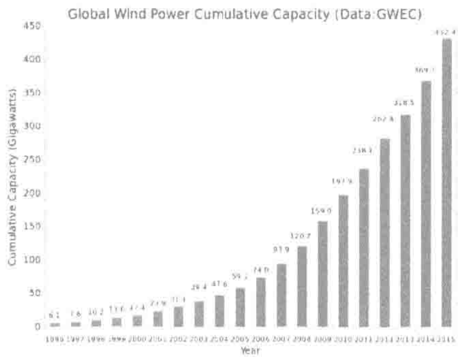
Wind power stations in Xinjiang, China

Wind power is the use of air flow through wind turbines to mechanically power generators for electricity. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, uses no water, and uses little land. The net effects on the environment are far less problematic than those of nonrenewable power sources.

Wind farms consist of many individual wind turbines which are connected to the electric power transmission network. Onshore wind is an inexpensive source of electricity, competitive with or in many places cheaper than coal or gas plants. Offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance costs are considerably higher. Small onshore wind farms can feed some energy into the grid or provide electricity to isolated off-grid locations.

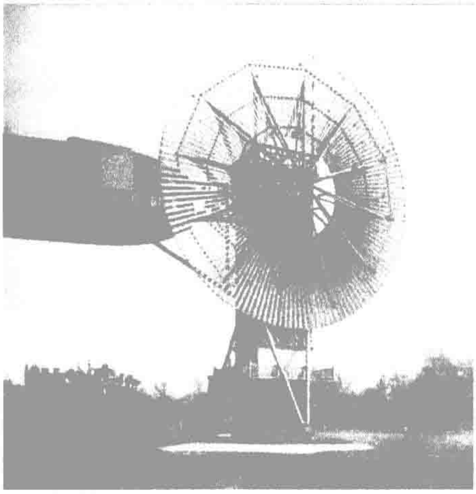
Wind power gives variable power which is very consistent from year to year but which has significant variation over shorter time scales. It is therefore used in conjunction with other electric power sources to give a reliable supply. As the proportion of wind power in a region increases, a need to upgrade the grid, and a lowered ability to supplant conventional production can occur. Power management techniques such as having excess capacity, geographically distributed turbines, dispatchable backing sources, sufficient hydroelectric power, exporting and importing power to neighboring areas, using vehicle-to-grid strategies or reducing demand when wind production is low, can in many cases overcome these problems. In addition, weather forecasting permits the electricity network to be readied for the predictable variations in production that occur.

As of 2015, Denmark generates 40% of its electricity from wind, and at least 83 other countries around the world are using wind power to supply their electricity grids. In 2014 global wind power capacity expanded 16% to 369,553 MW. Yearly wind energy production is also growing rapidly and has reached around 4% of worldwide electricity usage, 11.4% in the EU.



Global growth of installed capacity

History



Charles Brush's windmill of 1888, used for generating electricity.

Wind power has been used as long as humans have put sails into the wind. For more than two millennia wind-powered machines have ground grain and pumped water. Wind power was widely available and not confined to the banks of fast-flowing streams, or later, requiring sources of fuel. Wind-powered pumps drained the polders of the Netherlands, and in arid regions such as the American mid-west or the Australian out-back, wind pumps provided water for live stock and steam engines.

The first windmill used for the production of electricity was built in Scotland in July 1887 by Prof James Blyth of Anderson's College, Glasgow (the precursor of Strathclyde University). Blyth's 10 m high, cloth-sailed wind turbine was installed in the garden of his holiday cottage at Marykirk in Kincardineshire and was used to charge accumulators developed by the Frenchman Camille Alphonse Faure, to power the lighting in the cottage, thus making it the first house in the world to have its electricity supplied by wind power. Blyth offered the surplus electricity to the people of Marykirk for lighting the main street, however, they turned down the offer as they thought electricity was "the work of the devil." Although he later built a wind turbine to supply emergency power to the local Lunatic Asylum, Infirmary and Dispensary of Montrose the invention never really caught on as the technology was not considered to be economically viable.

Across the Atlantic, in Cleveland, Ohio a larger and heavily engineered machine was designed and constructed in the winter of 1887–1888 by Charles F. Brush, this was built by his engineering company at his home and operated from 1886 until 1900. The Brush wind turbine had a rotor 17 m (56 foot) in diameter and was mounted on an 18 m (60 foot) tower. Although large by today's standards, the machine was only rated at 12 kW. The connected dynamo was used either to charge a bank of batteries or to operate up to 100 incandescent light bulbs, three arc lamps, and various motors in Brush's laboratory.

With the development of electric power, wind power found new applications in lighting buildings remote from centrally-generated power. Throughout the 20th century parallel paths developed small wind stations suitable for farms or residences, and larger utility-scale wind generators that could be connected to electricity grids for remote use of power. Today wind powered generators operate in every size range between tiny stations for battery charging at isolated residences, up to near-gigawatt sized offshore wind farms that provide electricity to national electrical networks.

Wind Farms

Large onshore wind farms		
Wind farm	Current capacity (MW)	Country
Gansu Wind Farm	6,000	China
Muppandal wind farm	1,500	India
Alta (Oak Creek-Mojave)	1,320	United States
Jaisalmer Wind Park	1,064	India
Shepherds Flat Wind Farm	845	United States
Roscoe Wind Farm	782	United States
Horse Hollow Wind Energy Center	736	United States

Large onshore wind farms		
Wind farm	Current capacity (MW)	Country
Capricorn Ridge Wind Farm	662	United States
Fântânele-Cogealac Wind Farm	600	Romania
Fowler Ridge Wind Farm	600	United States
Whitelee Wind Farm	539	United Kingdom

A wind farm is a group of wind turbines in the same location used for production of electricity. A large wind farm may consist of several hundred individual wind turbines distributed over an extended area, but the land between the turbines may be used for agricultural or other purposes. For example, Gansu Wind Farm, the largest wind farm in the world, has several thousand turbines. A wind farm may also be located offshore.

Almost all large wind turbines have the same design — a horizontal axis wind turbine having an upwind rotor with three blades, attached to a nacelle on top of a tall tubular tower.

In a wind farm, individual turbines are interconnected with a medium voltage (often 34.5 kV), power collection system and communications network. In general, a distance of 7D (7 × Rotor Diameter of the Wind Turbine) is set between each turbine in a fully developed wind farm. At a substation, this medium-voltage electric current is increased in voltage with a transformer for connection to the high voltage electric power transmission system.

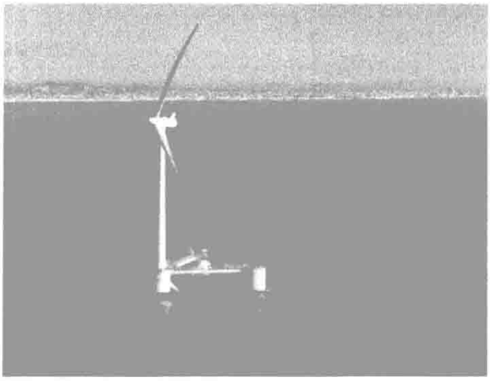
Generator Characteristics and Stability

Induction generators, which were often used for wind power projects in the 1980s and 1990s, require reactive power for excitation so substations used in wind-power collection systems include substantial capacitor banks for power factor correction. Different types of wind turbine generators behave differently during transmission grid disturbances, so extensive modelling of the dynamic electromechanical characteristics of a new wind farm is required by transmission system operators to ensure predictable stable behaviour during system faults. In particular, induction generators cannot support the system voltage during faults, unlike steam or hydro turbine-driven synchronous generators.

Today these generators aren't used any more in modern turbines. Instead today most turbines use variable speed generators combined with partial- or full-scale power converter between the turbine generator and the collector system, which generally have more desirable properties for grid interconnection and have Low voltage ride through-capabilities. Modern concepts use either doubly fed machines with partial-scale converters or squirrel-cage induction generators or synchronous generators (both permanently and electrically excited) with full scale converters.

Transmission systems operators will supply a wind farm developer with a grid code to specify the requirements for interconnection to the transmission grid. This will include power factor, constancy of frequency and dynamic behaviour of the wind farm turbines during a system fault.

Offshore Wind Power



The world's second full-scale floating wind turbine (and first to be installed without the use of heavy-lift vessels), WindFloat, operating at rated capacity (2 MW) approximately 5 km offshore of Póvoa de Varzim, Portugal

Offshore wind power refers to the construction of wind farms in large bodies of water to generate electricity. These installations can utilize the more frequent and powerful winds that are available in these locations and have less aesthetic impact on the landscape than land based projects. However, the construction and the maintenance costs are considerably higher.

Siemens and Vestas are the leading turbine suppliers for offshore wind power. DONG Energy, Vattenfall and E.ON are the leading offshore operators. As of October 2010, 3.16 GW of offshore wind power capacity was operational, mainly in Northern Europe. According to BTM Consult, more than 16 GW of additional capacity will be installed before the end of 2014 and the UK and Germany will become the two leading markets. Offshore wind power capacity is expected to reach a total of 75 GW worldwide by 2020, with significant contributions from China and the US.

In 2012, 1,662 turbines at 55 offshore wind farms in 10 European countries produced 18 TWh, enough to power almost five million households. As of August 2013 the London Array in the United Kingdom is the largest offshore wind farm in the world at 630 MW. This is followed by Gwynt y Môr (576 MW), also in the UK.

World's largest offshore wind farms				
Wind farm	Capacity (MW)	Country	Turbines and model	Commissioned
London Array	630	United Kingdom	175 × Siemens SWT-3.6	2012

World's largest offshore wind farms				
Wind farm	Capacity (MW)	Country	Turbines and model	Commissioned
Gwynt y Môr	576	United Kingdom	160 × Siemens SWT-3.6 107	2015
Greater Gabbard	504	United Kingdom	140 × Siemens SWT-3.6	2012
Anholt	400	Denmark	111 × Siemens SWT-3.6–120	2013
BARD Offshore 1	400	Germany	80 BARD 5.0 turbines	2013

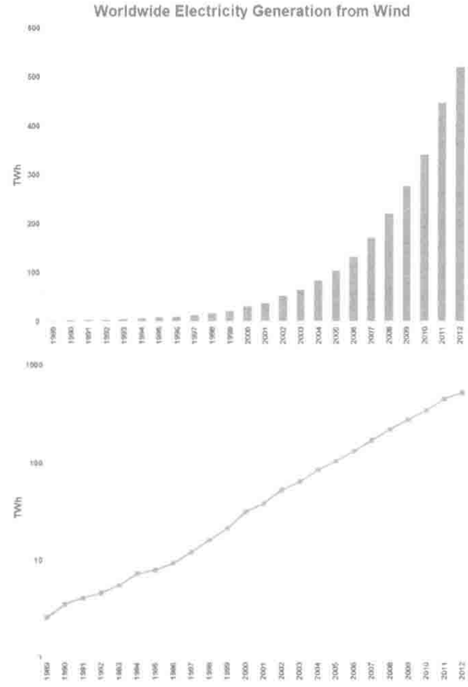
Collection and Transmission Network

In a wind farm, individual turbines are interconnected with a medium voltage (usually 34.5 kV) power collection system and communications network. At a substation, this medium-voltage electric current is increased in voltage with a transformer for connection to the high voltage electric power transmission system.

A transmission line is required to bring the generated power to (often remote) markets. For an off-shore station this may require a submarine cable. Construction of a new high-voltage line may be too costly for the wind resource alone, but wind sites may take advantage of lines installed for conventionally fueled generation.

One of the biggest current challenges to wind power grid integration in the United States is the necessity of developing new transmission lines to carry power from wind farms, usually in remote lowly populated states in the middle of the country due to availability of wind, to high load locations, usually on the coasts where population density is higher. The current transmission lines in remote locations were not designed for the transport of large amounts of energy. As transmission lines become longer the losses associated with power transmission increase, as modes of losses at lower lengths are exacerbated and new modes of losses are no longer negligible as the length is increased, making it harder to transport large loads over large distances. However, resistance from state and local governments makes it difficult to construct new transmission lines. Multi state power transmission projects are discouraged by states with cheap electricity rates for fear that exporting their cheap power will lead to increased rates. A 2005 energy law gave the Energy Department authority to approve transmission projects states refused to act on, but after an attempt to use this authority, the Senate declared the department was being overly aggressive in doing so. Another problem is that wind companies find out after the fact that the transmission capacity of a new farm is below the generation capacity, largely because federal utility rules to encourage renewable energy installation allow feeder lines to meet only minimum standards. These are important issues that need to be solved, as when the transmission capacity does not meet the generation capacity, wind farms are forced to produce below their full potential or stop running all together, in a process known as curtailment. While this leads to potential renewable generation left untapped, it prevents possible grid overload or risk to reliable service.

Wind Power Capacity and Production



Worldwide wind generation up to 2012 (Source EIA, January 2015).

Worldwide there are now over two hundred thousand wind turbines operating, with a total nameplate capacity of 432,000 MW as of end 2015. The European Union alone passed some 100,000 MW nameplate capacity in September 2012, while the United States surpassed 75,000 MW in 2015 and China's grid connected capacity passed 145,000 MW in 2015.

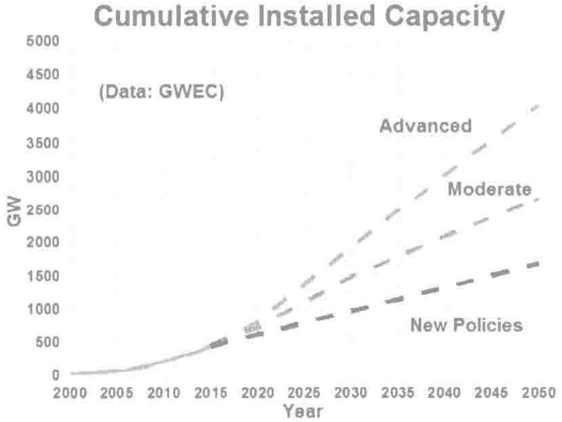
World wind generation capacity more than quadrupled between 2000 and 2006, doubling about every three years. The United States pioneered wind farms and led the world in installed capacity in the 1980s and into the 1990s. In 1997 installed capacity in Germany surpassed the U.S. and led until once again overtaken by the U.S. in 2008. China has been rapidly expanding its wind installations in the late 2000s and passed the U.S. in 2010 to become the world leader. As of 2011, 83 countries around the world were using wind power on a commercial basis.

Wind power capacity has expanded rapidly to 336 GW in June 2014, and wind energy production was around 4% of total worldwide electricity usage, and growing rapidly. The actual amount of electricity that wind is able to generate is calculated by multiplying the nameplate capacity by the capacity factor, which varies according to equipment and location. Estimates of the capacity factors for wind installations are in the range of 35% to 44%.

Europe accounted for 48% of the world total wind power generation capacity in 2009. In 2010, Spain became Europe's leading producer of wind energy, achieving 42,976 GWh. Germany held the top spot in Europe in terms of installed capacity, with a total of 27,215 MW as of 31 December 2010. In 2015 wind power constituted 15.6% of all installed power generation capacity in the EU and it generates around 11.4% of its power.

Top windpower electricity producing countries in 2012 (TWh)		
Country	Windpower Production	% of World Total
United States	140.9	26.4
China	118.1	22.1
Spain	49.1	9.2
Germany	46.0	8.6
India	30.0	5.6
United Kingdom	19.6	3.7
France	14.9	2.8
Italy	13.4	2.5
Canada	11.8	2.2
Denmark	10.3	1.9
(rest of world)	80.2	15.0
World Total	534.3 TWh	100%
Source:Observ'ER – Electricity Production From Wind Sources [2012]		

Growth Trends



Worldwide installed wind power capacity forecast (Source: Global Wind Energy Council)

After setting new records in 2014, the wind power industry surprised many observers with another record breaking year in 2015, chalking up 22% annual market growth and passing the 60 GW mark for the first time in a single year; and this after having broken the 50 GW mark for the first time in 2014. In 2015, close to half of all new wind