普通高等教育"十二五"规划教材

# 风力发电专业英语

主　编　陈铁华　曾　燕
副主编　杨家胜　刘海波

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## 内 容 提 要

本书涵盖了风力发电专业领域中的基础知识和专业知识，用于培养风能动力工程专业学生的专业英语阅读能力，同时也是学习风力发电知识的好素材。书中正文和练习材料全部来自英文原版书籍，涉及的专业知识面广泛，内容丰富，专业特点突出。全书共16章，分别讲述了风能利用历史，风能基本概念，风力机基本原理及性能、风力机主要部件及设计，风力机组控制策略，风力发电机、风力发电机接入电网、电力系统、塔架及风电场等。每篇文章后还介绍了科技英语翻译基本知识及要领。

本书具有较强的实用性和知识性，既可作为高等学校新能源科学与工程专业、风能与动力工程专业英语教材，也可供风电领域相关技术人员学习、参考使用。

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# 前　言

我国虽然是对风能利用最早的国家，但利用风来发电，首先还是国外最先开始的。在20世纪30年代，丹麦、瑞典、苏联和美国应用航空工业的旋翼技术，成功地研制了一些小型风力发电装置。1978年1月，美国在新墨西哥州的克莱顿镇建成的200kW风力发电机，其叶片直径为38m，发电量足够60户居民用电。而1978年初夏，在丹麦日德兰半岛西海岸投入运行的风力发电装置，其发电量则达2000kW，风车高57m，所发电量的75%送入电网，其余供给附近的一所学校用。

在过去的几十年里，随着全球气候变暖和能源危机的出现，各国都加紧了对风能的开发和利用。随着风力发电规模的扩大，风电技术迅速成熟与提高，国外相应出版了大量风电技术图书供风电技术人员参考和节能爱好者学习。

我国风电技术由于受到国家政策及能源发展趋势的影响也迅猛发展起来，并吸引了大量科技工作者投身到风力发电领域，从事科研、设计、建设、运行与维护。为了使风电科技工作者及风能专业学生既学习到风能理论，又阅读到地道的英文表述方式，出版了本书。本书从众多国外原版技术图书中选取了具有代表性的文章，内容包括风能利用历史、风能基本概念、风力机概述、空气动力学基本理论、翼面的升力和阻力、风力机基本性能、传递系统、风力机结构设计、风力机偏航与变桨控制、风力机安全与控制系统、不同型式风力机控制策略、风力发电机、风力发电并网、电力系统、塔架及风电场等16篇文章，比较全面地涵盖了风力发电领域涉及的技术内容。同时，为了帮助读者阅读英文科技文献，掌握科技英语阅读要领，每篇文章后附有科技英文翻译要点，附录中列举了英文常用的数、时间及符号的表达与读法等内容供读者参考。

本书由长春工程学院陈铁华、曾燕担任主编，负责全书英文内容的选材，统稿及审核。全书课文注释及专业词汇短语编辑工作由长春工程学院曾燕负责8～11单元，陈铁华负责12～14单元，长江勘测规划设计研究有限责任公司杨家胜负责3～7单元，刘海波负责前言及1～2、15～16单元。每单元的科技英语阅读及翻译技巧由曾燕负责。

由于风力发电技术尚属于新兴技术，风电专业英语教材也是第一次出版，对一些专业术语的理解难免有不妥及不当的地方，衷心希望读者批评指正，并敬请读者在使用过程中将意见及建议及时反馈给我们，以便再版时进行更正。

**编者**

2012年6月

# 目　　录

# Preface

The wind is a free, clean, and inexhaustible energy source. It has served mankind well for many centuries by propelling ships and driving wind turbines to grind grain and pump water. Interest in wind power lagged, however, when cheap and plentiful petroleum ducts became available after World War Ⅱ. The high capital costs and the uncertainty of the wind placed wind power at an economic disadvantage. Then in 1973, the Arab nations placed an embargo on petroleum. The days of cheap and plentiful petroleum were drawing to an end.

People began to realize that the world's oil supplies would not last forever and that remaining supplies should be conserved for the ***petrochemical industry***（石油化学工业）. The use of oil as a boiler fuel, for example, would have to be eliminated. Other energy sources besides oil and natural gas must be developed.

The two energy sources besides petroleum which have been assumed able to supply the long term energy needs of mankind are coal and nuclear energy. Many people think there is enough coal for several centuries at present rates of consumption, and likewise for nuclear energy after the ***breeder reactor***（核能反应堆）is fully developed. These are proven resources in the sense that the technology is highly developed and large coal and nuclear powered electrical generating plants are in operation and are delivering substantial blocks of energy to the consumer. Unfortunately, both coal and nuclear presented serious environmental problems.

Coal requires large scale mining operations, leaving land that is difficult or impossible to restore to usefulness in many cases. The combustion of coal may upset the planet's heat balance. The production of ***carbon dioxide***（二氧化碳）and ***sulfur dioxide***（二氧化硫）may affect the atmosphere and the ability of the planet to produce food for its people. Coal is also a valuable petrochemical feedstock and many consider the burning of it as a boiler fuel to be foolish.

Nuclear energy has several advantages over coal in that no carbon dioxide or sulfur dioxide are produced, mining operations are smaller scale, and it has no other major use besides supplying heat. The major difficulty is the problem of waste disposal, which, because of the fears of many, will probably never have a truly satisfying solution.

Because of these problems, wind power and other forms of solar power are being strongly encouraged. Wind power may become a major source of energy in spite of slightly higher costs than coal or nuclear power because of the basically non-economic or political problems of coal and nuclear power. This is not to say that wind power will always be more expensive than coal or nuclear power, because considerable progress is being made in making wind power less expensive. But even without a clear cost advantage, wind power may become truly important in the world energy picture.

Motivated by the high dependence of global economies on fossil fuels and the concern about the environment, increasing attention is being paid to alternative methods of electricity generation. In this trend towards the diversification of the energy market, wind power is probably the most promising sustainable energy resource. The wind is a clean and inexhaustible resource available all over the world. Recent progress in wind technology has led to cost reductions to cost levels comparable, in many cases, with conventional methods of electricity generation. Further, the number of wind turbines coming into operation increases significantly year after year.

Wind energy conversion is hindered by the intermittent and seasonal variability of the primary resource. For this reason, wind turbines usually work with low conversion efficiency and have to withstand heavy ***aerodynamic loads***（气动载荷）, which deteriorate the power quality. In spite of this, wind turbines with rudimentary control systems predominated for a long time, the prevailing goal being the minimization of the cost and maintenance of the installation. More recently, the increasing size of the turbines and the greater penetration of wind energy into the utility networks of leading countries have encouraged the use of electronic converters and mechanical actuators❶. These active devices have incorporated extra degrees of freedom to the design that opened the door to active control of the captured power❷. Static converters used as an interface to the electric grid enable variable-speed operation, at least up to ***rated speed***（额定速度）. In addition to increasing the energy capture, variable-speed turbines can be controlled to reduce the loading on the drive-train and tower structure, leading to potentially longer installation life. Increasingly, modern wind turbines include mechanical actuators with the aim of having control of the ***blade pitch angle***（叶片桨距角）. ***Pitch control***（桨距控制）is commonly meant to limit the captured power above rated wind speed, bringing about more cost-effective designs. The higher complexity of ***variable-speed variable-pitch turbines***（变速变桨距风力机）is largely offset by the benefits of control flexibility, namely higher conversion efficiency, better power quality, longer useful life, etc❸. Thus, control has an immediate impact on the cost of wind energy. Moreover, high performance and reliable controllers are essential to enhance the competitiveness of wind technology. The rapid development of control technology has an impact on all areas of the control discipline. New theory, new controllers, actuators, sensors, new industrial processes, computer methods, new applications, new philosophies, new challenges, much of this development work resides in industrial reports, feasibility study papers and the reports of advanced collaborative projects.

The use of wind energy to generate electricity is now well accepted with a large industry manufacturing and installing thousands of MWs of new capacity each year. Although there are exciting new developments, particularly in very large wind turbines, and many challenges remain, there is a considerable body of established knowledge concerning the science and technology of wind turbines.

This book is intended to record some of this knowledge and to present it in a form suitable for use by students and by those involved in the design, manufacture or operation of wind turbines. The overwhelming majority of wind turbines presently in use are horizontal-axis, land-based turbines connected to a large electricity network. These turbines are the subject of this book.

## Vocabularies

*petrochemical industry* [ˌpetrəʊ'kemɪkəl] 石油化学工业
*breeder reactor* 核能反应堆
*carbon dioxide* 二氧化碳
*sulfur dioxide* 二氧化硫
*rated speed* 额定速度
*aerodynamic load* [ˌeərəʊdaɪ'næmɪk] 气动载荷
*blade pitch angle* 叶片桨距角
*pitch control* 桨距控制
*variable-speed variable-pitch turbine* 变速变桨距风力机

## Notes

❶ More recently, the increasing size of the turbines and the greater penetration of wind energy into the utility networks of leading countries have encouraged the use of electronic converters and mechanical actuators.

目前，随着风力机尺寸的不断增加，以及风能在先进国家公共网络中地渗透，极大地促进了电子转换器和机械执行机构的应用。

❷ These active devices have incorporated extra degrees of freedom to the design that opened the door to active control of the captured power.

这些执行机构在设计中结合了额外的自由度，这样就找到了主动控制风能捕获的途径。

❸ The higher complexity of variable-speed variable-pitch turbines is largely offset by the benefits of control flexibility, namely higher conversion efficiency, better power quality, longer useful life, etc.

变速变桨距风力机越复杂，控制灵活性带来的效益越大，也就是说转换效率越高，电能质量越好，使用寿命越长。

# 1 Scope of Wind Power

## 1.1 Historical Development

Windmills have been used for at least 3000 years, mainly for grinding grain or pumping water, while in sailing ships the wind has been an essential source of power for even longer. From as early as the thirteenth century, ***horizontal-axis windmills***（水平轴风力机）were an integral part of the rural economy and only fell into disuse with the advent of cheap fossil-fuelled engines and then the spread of ***rural electrification***（农村电气化）.

The use of windmills (or wind turbines) to generate electricity can be traced back to the late nineteenth century with the 12 kW DC windmill generator constructed by Brush in the USA and the research undertaken by LaCour in Denmark. However, for much of the twentieth century there was little interest in using wind energy other than for battery charging for remote dwellings and these low-power systems were quickly replaced once access to the ***electricity grid***（电网）became available[❶]. One notable exception was the 1250 kW Smith-Putnam wind turbine constructed in the USA in 1941. This remarkable machine had a steel rotor 53 m in diameter, full-span ***pitch control***（桨距控制）and flapping blades to reduce loads. Although a blade spar failed ***catastrophically***（灾难性地）in 1945, it remained the largest wind turbine constructed for some 40 years. Golding (1955) and Shepherd and Divone in Spera (1994) provide a fascinating history of early wind turbine development. They record the 100 kW 30 m diameter Balaclava wind turbine in the then USSR in 1931 and the Andrea Enfield 100 kW 24 m diameter ***pneumatic***（气动的）design constructed in the UK in the early 1950s. In Denmark the 200 kW 24 m diameter Gedser machine was built in 1956 while Electricite' de France tested a 1.1 MW 35 m diameter turbine in 1963. In Germany, Professor Hutter constructed a number of innovative, lightweight turbines in the 1950s and 1960s. In spite of these technical advances and the enthusiasm, among others, of Golding at the Electrical Research Association in the UK there was little sustained interest in wind generation until the price of oil rose dramatically in 1973.

The sudden increase in the price of oil stimulated a number of substantial Government-funded programs of research, development and demonstration. In the USA this led to the construction of a series of ***prototype turbines***（原型风轮机）starting with the 38 m diameter 100 kW Mod-0 in 1975 and culminating in the 97.5 m diameter 2.5 MW Mod-5B in 1987. Similar programs were pursued in the UK, Germany and Sweden. There was considerable uncertainty as to which architecture might prove most cost-effective and several innovative concepts were investigated at full scale. In Canada, a 4 MW ***vertical-axis Darrieus wind turbine***（立式达里厄风机）was constructed and this concept was also investigated in the 34 m diameter ***Sandia Vertical Axis Test Facility in the USA***（美国山迪亚垂直轴测试设备）. In the UK, an alternative vertical-axis design using straight blades to give an 'H' type rotor was proposed by Dr Peter Musgrove and a 500 kW prototype constructed. In 1981 an innovative horizontal-axis 3 MW wind turbine was built and tested in the USA. This used ***hydraulic transmission***（液压传动）and, as an alternative to a ***yaw drive***（偏航驱动）, the entire structure was orientated into the wind. The best choice for the number of blades remained unclear for some while and large turbines were constructed with one, two or three blades.

Much important scientific and engineering information was gained from these Government-funded research programs and the prototypes generally worked as designed. However, it has to be recognized that the problems of operating very large wind turbines, unmanned and in difficult wind climates were often under estimated and the reliability of the prototypes was not good❷. At the same time as the multi-megawatt prototypes were being constructed private companies, often with considerable state support, were constructing much smaller, often simpler, turbines for commercial sale. In particular the financial support mechanisms in California in the mid-1980s resulted in the installation of a very large number of quite small (< 100 kW) wind turbines. A number of these designs also suffered from various problems but, being smaller, they were in general easier to repair and modify. The so-called 'Danish' wind turbine concept emerged of a three-bladed, ***stall-regulated***（失速控制）rotor and a fixed-speed, ***induction machine***（感应电机）drive train. This deceptively simple architecture has proved to be remarkably successful and has now been implemented on turbines as large as 60 m in diameter and at ratings of 1.5 MW. The machine of Fig. 1.1 is an example of this design. However, as the sizes of commercially available turbines now approach that of the large prototypes of the 1980s it is interesting to see that the concepts investigated then of variable-speed operation, full-span control of the blades, and advanced materials are being used increasingly by designers❸. In this design, the ***synchronous generator***（同步发电机）is coupled directly to the ***aerodynamic rotor***（气动转子）so eliminating the requirement for a gearbox.

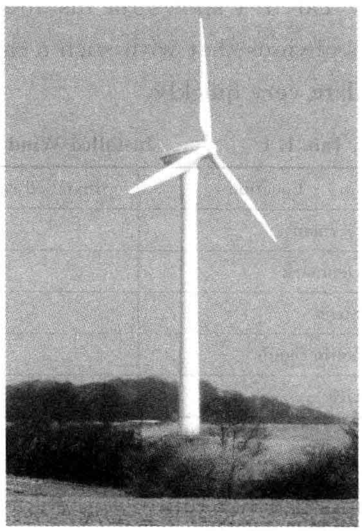

Fig. 1.1 1.5 MW, 64 m Diameter Wind Turbine

The stimulus for the development of wind energy in 1973 was the price of oil and concern over limited fossil-fuel resources. Now, of course, the main driver for use of wind turbines to generate electrical power is the very low $CO_2$ emissions (over the entire life cycle of manufacture, installation, operation and de-commissioning) and the potential of wind energy to help limit climate change. In 1997 the Commission of the European Union published its ***White Paper*** (白皮书) (CEU, 1997) calling for 12 percent of the gross energy demand of the European Union to be contributed from renewable by 2010. Wind energy was identified as having a key role to play in the supply of ***renewable energy*** (再生能源) with an increase in installed wind turbine capacity from 2.5 GW in 1995 to 40 GW by 2010❶. This target is likely to be achievable since at the time of writing, January 2001, there was some 12 GW of installed wind-turbine capacity in Europe, 2.5 GW of which was constructed in 2000 compared with only 300 MW in 1993. The average annual growth rate of the installation of wind turbines in Europe from September 1993 was approximately 40 percent. The distribution of wind-turbine capacity is interesting with, in 2000, Germany accounting for some 45 percent of the European total, and Denmark and Spain each having approximately 18 percent. There is some 2.5 GW of capacity installed in the USA of which 65 percent is in California although with increasing interest in Texas and some states of the mid-west. Many of the California wind farms were originally constructed in the 1980s and are now being re-equipped with larger modern wind turbines.

Tab. 1.1 shows the installed wind-power capacity worldwide in January 2001 although it is obvious that with such a rapid growth in some countries data of this kind become out of date very quickly.

**Tab. 1.1 Installed Wind Turbine Capacity Throughout the World, 2001**

| Location | Installed capacity (MW) | Location | Installed capacity (MW) |
|---|---|---|---|
| Germany | 5432 | Total Europe | 11831 |
| Denmark | 2281 | California | 1622 |
| Spain | 2099 | Total USA | 2568 |
| Netherlands | 444 | Total World | 16461 |
| UK | 391 | | |

The reasons development of wind energy in some countries is flourishing while in others it is not fulfilling the potential that might be anticipated from a simple consideration of the wind resource, are complex. Important factors include the financial-support mechanisms for wind-generated electricity, the process by which the local planning authorities give permission for the construction of wind farms, and the perception of the general population particularly with respect to visual impact. In order to overcome the concerns of the rural population over the environmental impact of wind farms there is now increasing interest in the development of sites offshore.

## 1.2 Modern Wind Turbines

A wind turbine is a machine which converts the power in the wind into electricity. This is in contrast to a 'windmill', which is a machine which converts the wind's power into mechanical power. As electricity generators, wind turbines are connected to some electrical network. These networks include battery charging circuits, residential scale power systems, isolated or island networks, and large utility grids. In terms of total numbers, the most frequently found wind turbines are actually quite small—on the order of 10 kW or less. In terms of total generating capacity, the turbines that make up the majority of the capacity are in general rather large—in the range of 500 kW to 2 MW. These larger turbines are used primarily in large utility grids, mostly in Europe and the United States.

To understand how wind turbines are used, it is useful to briefly consider some of the fundamental facts underlying their operation. In modern wind turbines, the actual conversion process uses the basic aerodynamic force of lift to produce a net positive torque on a rotating shaft, resulting first in the production of mechanical power and then in its transformation to electricity in a generator. Wind turbines, unlike almost every other generator, can produce energy only in response to the wind that is immediately available. It is not possible to store the wind and use it a later time. The output of a wind turbine is thus inherently fluctuating and non-dispatchable. (The most one can do is to limit production below what the wind could produce.) Any system to which a wind turbine is connected must in some way take this variability into account. In larger networks, the wind turbine serves to reduce the total electrical load and thus results in a decrease in either the number of conventional generators being used or in the fuel use of those that are running. In smaller networks, there may be energy storage, backup generators, and some specialized control systems. A further fact is that the wind is not transportable: it can only be converted where it is blowing. Historically, a product such as ground wheat was made at the windmill and then transported to its point of use. Today, the possibility of conveying electrical energy via power lines compensates to some extent for wind's inability to be transported. In the future, hydrogen-based energy systems may add to this possibility.

### 1.2.1 Modern Wind Turbine Design

Today, the most common design of wind turbine, and the only kind discussed in any detail in this book, is the horizontal axis wind turbine (HAWT). That is, the axis of rotation is parallel to the ground. HAWT rotors are usually classified according to the rotor orientation (upwind or downwind of the tower), hub design (rigid or teetering), rotor control (pitch vs. stall), number of blades (usually two or three blades), and how