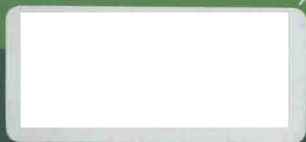


THE ART AND SCIENCE OF
WIND POWER



David A. Rivkin
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Laurel Silk

Wind Power Generation and Distribution



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Preface

THE WIND ENERGY INDUSTRY is at the forefront of the world's shift away from reliance on fossil fuels. In just a few short decades wind energy has evolved dramatically. Technological advances now make wind energy a cost-effective solution for the world's ever-growing energy needs. The United States is now one of the world's leaders in overall wind power capacity.

As the wind energy industry continues to expand in the United States and around the globe, it will provide many opportunities for workers in search of new careers. These careers extend beyond the wind farm and include the efforts of employees who work in manufacturing plants, offices, and construction, as well as operation and maintenance. According to estimates from the American Wind Energy Association, approximately 85,000 Americans are currently employed in the wind power industry. Despite the growing demand for skilled workers, there remains a lack of serious educational resources to meet the market's demand.

The *Art and Science of Wind Power* series was developed to fill this educational gap. Each book in the series examines performance challenges using a systems perspective. Readers do not learn design and installation steps in a vacuum—instead they examine interrelationships and discover new ways to improve their own systems and positively contribute to the industry.

This series was developed for both the novice and expert. The texts take the learner from an overview of wind energy, through design and installation steps and considerations, to the design and installation of commercial wind systems.

Wind Power Generation and Distribution provides readers with information on electric motors and the installation and maintenance of wind turbines. Topics include energy conversion, power electronics, converters, generators, wind-turbine control, rotor dynamics, and wind farms.

About the Authors

Prof. David A. Rivkin, PhD, is managing director and dean of the College of Science and Technology at the Sustainable Methods Institute (SMI), an online university and innovation center.

He is also the chairman of the Department of Nanosciences in Renewable Energy at Chiist University, Atlanta, Georgia; and dean of education and research at the Israel Sustainability Institute. He is also chief scientist and director at the Adamah Group and its wind power division in Israel.

Professor Rivkin was the founder, associate professor, and chairman of the Green Technologies Department at Ohalo College of Katzrin; associate professor at National University, based in San Diego, Calif.; International Technological University, in San Jose, Calif.; and the Graduate School of Science and Technology at the Technical University of Munich, in Germany.

He holds dual bachelor's degrees in chemistry and nuclear engineering from the University of California at Berkeley. Professor Rivkin pursued postgraduate studies toward a doctorate in biophysics at the University of California and later completed a PhD in business sciences at the European School of Business London at Regent's College, with a focus on small business sustainability. He has over 25 years of professional experience in both industry and academia.

He has taught at internationally renowned colleges and universities in Europe, India, China, the United States, and Israel. In 2010 Professor Rivkin was nominated to be a Fulbright scholar. He is also an Institute of Electrical and Electronics Engineers (IEEE) senior member and distinguished lecturer, a principal adviser in clean technologies to the National Science Foundation, a certified program manager, a certified corporate sustainability expert, and a certified green energy professional.

He is the winner of numerous technical and managerial awards and has been recognized for his outstanding contributions by governments as well as the United Nations. A serial entrepreneur, with roles in several successful ventures, including

as founder and chief of technology for SciEssence International, Professor Rivkin has a multidisciplinary background, from biosciences to nanotechnology from health to energy, that gives him broad expertise in sustainability.

Marc Randall is a freelance writer and instructional designer currently living in Buenos Aires, Argentina. Born in New Mexico, he studied education at Colorado State University in Fort Collins, Colorado. He has been involved in print-based and online education for nearly a decade.

Laurel Silk has managed e-learning initiatives at three leading universities in Arizona including Arizona State University, University of Phoenix, and Grand Canyon University. Among the highlights of her career, she created a virtual doctoral library for research students and designed and implemented a web-based doctoral studies program in administration. Ms. Silk is a former classroom instructor, in which capacity she designed and taught courses in freshman English, world literature, and critical thinking. As vice president of SilkWeb, she has created undergraduate and graduate online courses in higher education, renewable energy, business, and nursing. Ms. Silk holds a Masters degree in education with a focus on adult learning and instructional design technologies from University of Phoenix and has a Bachelor of Arts in English from Arizona State University.

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Introduction: A History of Wind Power

FOR OVER 5,000 YEARS, wind has been a viable source of power, generating energy for a variety of purposes, ranging from sailboats to machinery. Wind power has been converting wind energy into useful and renewable energy as wind turbines for electricity, windmills for mechanical power, and wind pumps for water pumping or draining. The use of **wind** for sailing later inspired Greek engineer Heron of Alexandria to develop the first wind-powered machine in the first century AD—an organ **FIGURE 1**. Other ancient uses of wind include the prayer wheels of Tibet and China in the fourth century. Centuries followed before the first applied technology in wind power emerged with the invention of the windmill in the seventh to ninth centuries. The first practical windmill was built in Sistan (now eastern Iran); it was composed of a long, vertical **drive shaft** with rectangular blades and reed- or cloth-covered sails **FIGURE 2**. Though able to grind corn and pump water, this vertical design proved to be inefficient and highly susceptible to damage as the vertical axes of the rotors were driven by drag forces.

NATURE USES WIND TO POWER TRANSPORT

Nature has been using the power of the wind for millions of years to transport pollen and seeds to distant locations. Dandelion plants evolved specific lightweight seeds with parachute-like tops to catch the wind and be blown miles from their parent. Maple trees evolved propeller-like wings on their seeds not only to drop safely to the ground but

(Continues)

NATURE USES WIND TO POWER TRANSPORT (Continued)

also to be caught by the wind and blown far from the parent tree. Pollen grains are microscopically shaped to catch the wind and be carried for many hundreds of miles. From nature, we can learn a great deal about using the wind to provide us with power in many forms.

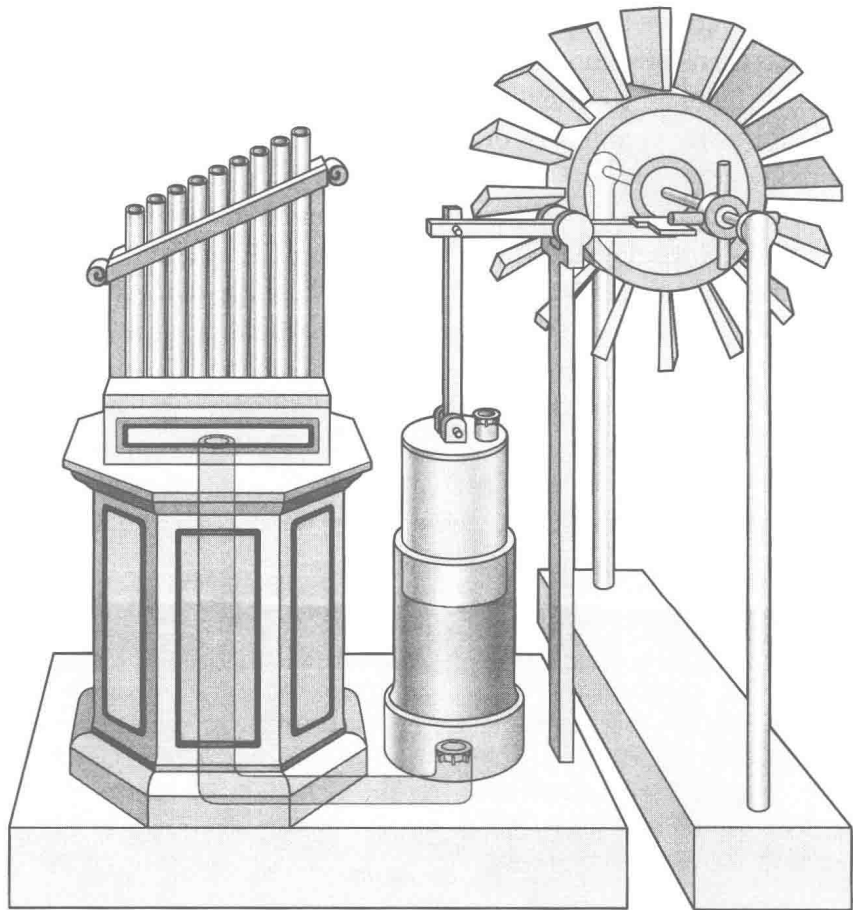


FIGURE 1 Heron's wind-powered organ.

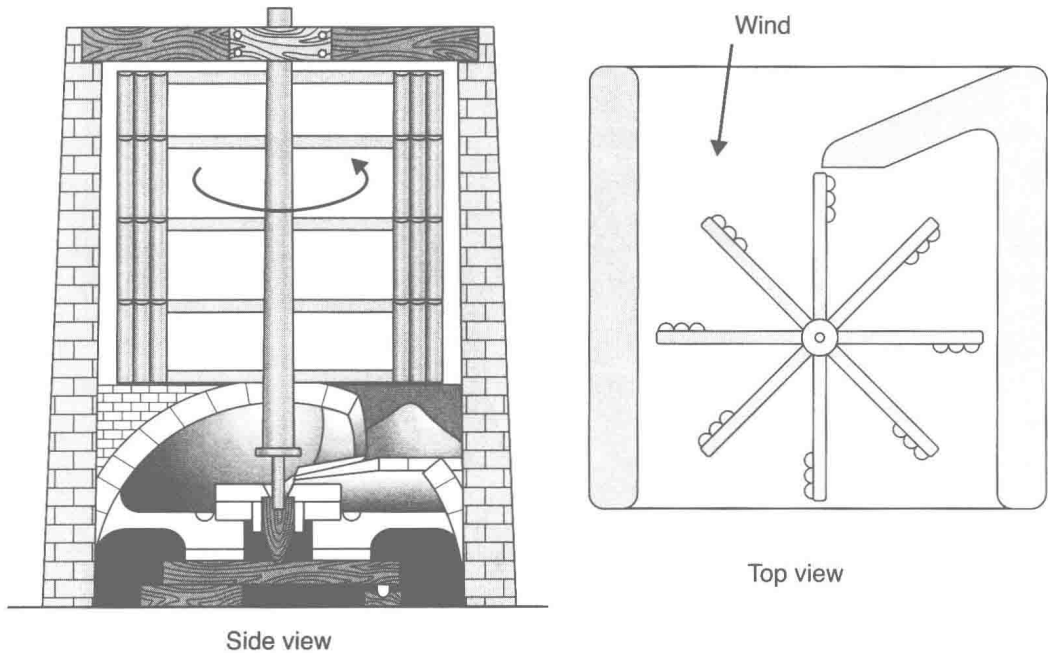


FIGURE 2 The top and side view of the Sistan windmill.

Courtesy of Kaboldy

It was not until the early twelfth through fourteenth centuries that Europe began using horizontal-axis windmills, which greatly improved the performance and maintenance of wind energy generation. Unlike water mills, wind-powered mills were not restricted to seasonal changes, such as water freezing in winter, and were not confined to the proximity of fast water streams. With about four blades, the first version of the European windmill was the post mill, which turned to face the wind (or **yaw**) depending on wind direction. Later versions (smock mills), as shown in **FIGURE 3**, improved the European design by keeping most of the mill stationary and making only the top portion movable to face the wind.

Further advancements in windmills in the eighteenth century spanned research and design into theory and development. In England, John Smeaton developed the three basic principles of windmill design that are still relevant today:

- The speed of the blade tips is ideally proportional to the speed of wind.
- The maximum torque is proportional to the speed of wind squared.
- The maximum power is proportional to the speed of wind cubed.

As uses for the windmill increased (e.g., pumping water for salt making), the demand for windmills reached large numbers in the late 1800s, with Denmark

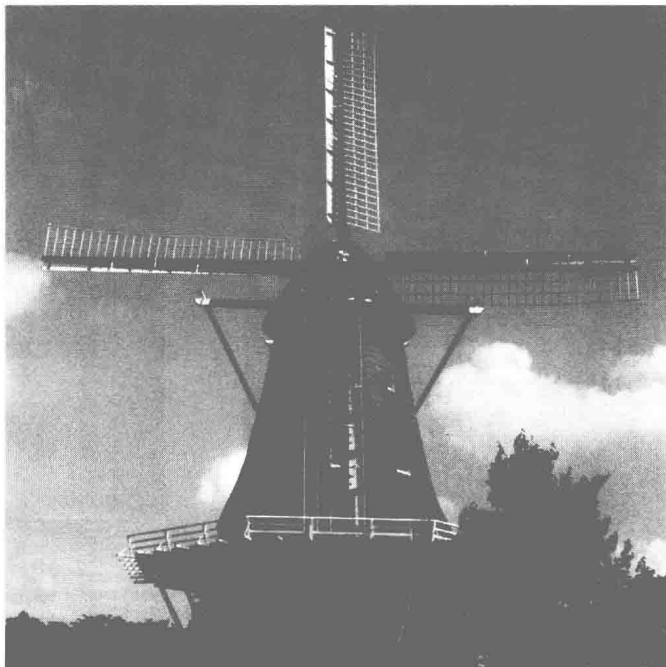


FIGURE 3 Smock mill in Amsterdam.

Courtesy of Aloxe Alix Guillard

establishing 2,500 windmills to offset their below-sea-level terrain, which was subject to frequent flooding. During the latter half of the nineteenth century, the American Midwest alone became the home to approximately 6 million “fan mills,” which provided advanced regulated irrigation (unattended for long periods) to small farms.

Beyond irrigation purposes, wind energy became part of a new branch of study—electrical science and engineering—at the advent of the Second Industrial Revolution. In 1887, Professor James Blyth of Scotland and Camille Fauré of France supplied the first wind-powered electricity to a cottage in Marykirk, Scotland. That same year in Cleveland, Ohio, Charles Brush built a massive wind-powered machine with a turbine **rotor** spanning 56 feet in diameter that was mounted on a 60-foot tower **FIGURE 4**. With 144 blades, this slow machine had an output of a mere 12 kilowatts (kW), which could power only about 100 light bulbs, three arc lamps, and some motors.

Electricity-generating wind turbines gained more momentum in the early 1900s. Based on the smock mills, Danish scientist Poul la Cour constructed over 100 electricity-generating turbines by converting the produced electricity to hydrogen gas, which was then used for lighting. Then, in 1927, the Jacobs brothers, Joe and Marcellus, became the first successful commercial producers of **wind**