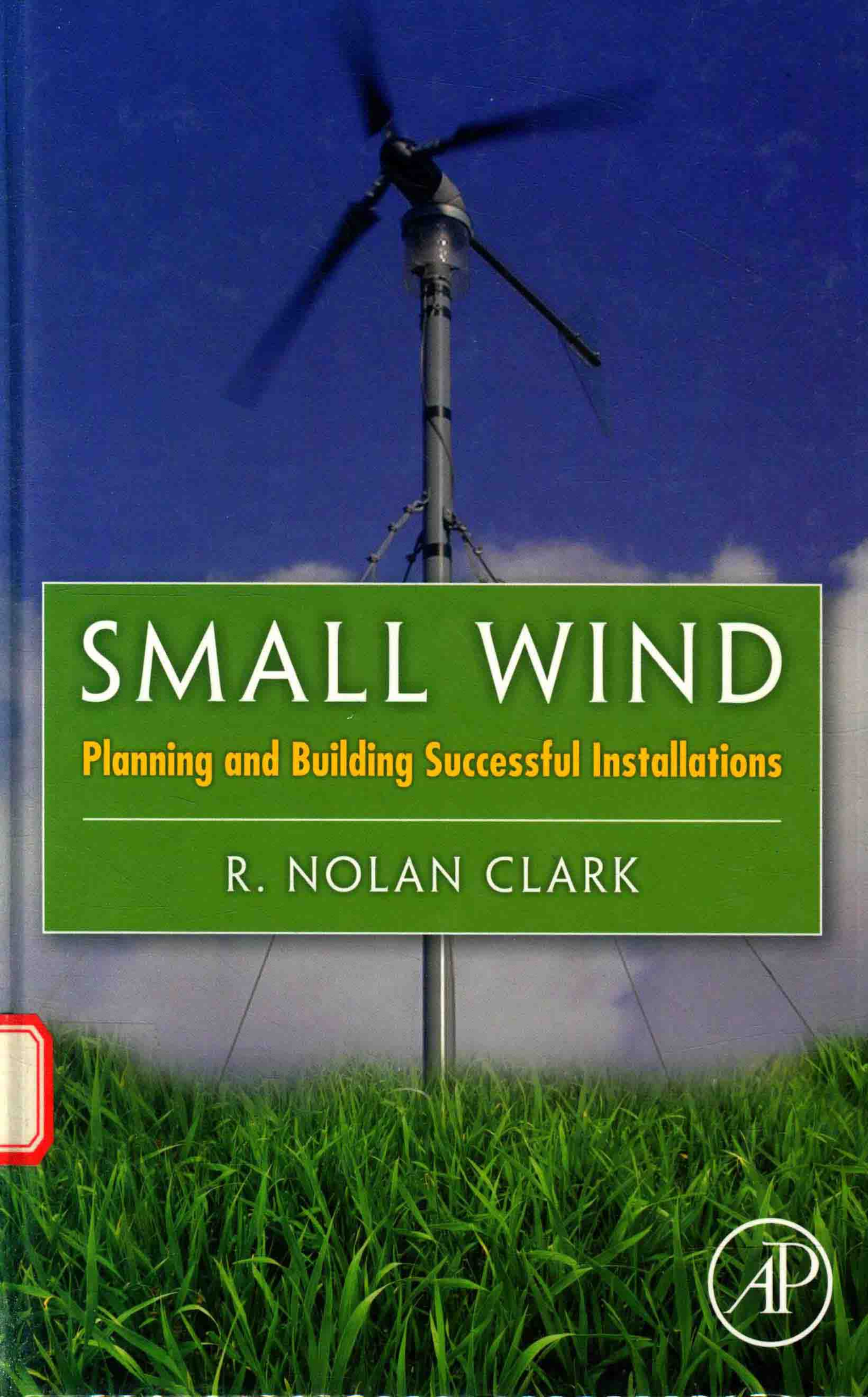

SMALL WIND

Planning and Building Successful Installations

R. NOLAN CLARK

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DEDICATION

This book is dedicated to all the men and women who contributed their time, expertise, and passion for small wind systems in writing the International Standard "Design Requirements for Small Wind Turbines, IEC 61400-2" and the British and American "Small Wind Turbine Performance and Safety Standards." These standards have established meaningful criteria for engineering design and standardized performance data to allow consumers to make informed purchases. Thank all of you for your hard work and determination in creating these important standards.

PREFACE

The word *small* is a relative term in that it often means something different to almost everyone. The size of small wind turbines has been changing since the beginning of the use of wind power to grind grain and pump water. Wind turbine sizes in today's small wind category include all but a handful of machines that were constructed prior to 1980. Some notable large wind turbines built before 1980 include the Smith–Putman built in 1941, the John Brown built in 1955, and the Gedser erected in 1957. Several countries in Europe were experimenting with larger wind turbines in the 1950s, but abandoned most development because of the abundance of low-cost petroleum. Many of the first wind turbines installed in wind farms in California, Denmark, and Germany during the mid-1980s had rotor diameters of approximately 15 m, which gave them a rotor area of just under 200 m^2 (2,200 ft^2). Everyone considered them large because they were much larger than the common electric battery–charging turbines sold in the 1930s and 1940s.

The first small wind turbine standard, developed by the International Electrotechnical Commission (IEC) in 1996, defined small wind turbines as those with a rotor area smaller than 40 m^2 (440 ft^2). They had a 7.2 m (24 ft) diameter and a power rating of approximately 13 kW at an 11 m/s wind speed. However, as wind turbines became larger in the early 2000s, the upper limit of small wind was questioned. When the IEC revised the small wind design standard in 2006, the rotor area was increased to 200 m^2 (2,200 ft^2), five times the earlier upper limit. A turbine with an area of 200 m^2 has a rotor diameter of 16 m (52 ft) and a power rating of 65 kW at a wind speed of 11 m/s. The British Wind Energy Association Small Wind Turbine Performance and Safety Standard also set the upper limit at 200 m^2. In 2009, when the AWEA Small Wind Turbine Performance and Safety Standard was adopted, the rotor area for small wind machines followed the IEC standard of 200 m^2. Not too long after that, the association changed their definition of small wind to include all turbines with a rotor capacity of 100 kW or less. A 100 kW wind turbine has a rotor area of 350 m^2 (3,850 ft^2) and a rotor diameter of 21 m (70 ft).

So the upper limit of small wind turbines has grown. As a result, the definition of "small" keeps changing as the wind industry matures and gains more experience with larger machines. The IEC has prepared a draft third revision for the small wind turbine design standard. In the new draft they retain the 200 m^2 upper limit for small wind turbines, which means that, for the next 10 years, we can expect the upper limit to remain the same as is currently.

There are many things to consider when choosing a small wind system either to provide electricity where none is available or to offset the purchase of expensive electricity. The two most important things to consider are the location of the turbine and the type of turbine to purchase. Selecting a proper site requires time to examine the wind speeds available, the permits required, and the land available to meet all safety and operational concerns. Selecting a wind turbine of sufficient size requires knowledge of the anticipated electric load that it will power, as well as knowing that it has been tested and is certified to meet performance and safety standards. It is hoped that the information in this book will help readers make the right choices and guide them in completing a successful installation.

ACKNOWLEDGMENTS

The assistance of Trudy Forsyth and Frank A. Oteri is greatly appreciated in writing the chapters on distributed wind systems and economic considerations. Trudy is retired from the National Renewable Energy Laboratory (NREL)/National Wind Technology Center, where she was a mechanical engineer V and the Distributed Wind Program lead. Frank is a contractor with Wind Powering America/NREL serving as communications specialist.

I thank all the engineers, scientists, manufacturers, policy makers, and research program managers for their candid discussions, criticism, and encouragement over the last 35 years as I led a small team conducting research and testing for the USDA–Agricultural Research Service in Bushland, Texas. I am grateful for all the opportunities I had to conduct research and development work with the engineers at Sandia National Laboratories and NREL and for their support for my research activities with mostly small wind systems.

I am especially thankful that the USDA–Agricultural Research Service developed a cooperative research program with the Alternative Energy Institute at West Texas A&M University at the beginning of the wind energy research program. Dr. Vaughn Nelson's contribution to the research activities was superb, along those of with Ken Starcher and many students.

I am deeply indebted to the engineering staff that work with me at the USDA–Agricultural Research Service in Bushland, especially Fred Vosper, Fadi Kamand, and Ron Davis, who were there in the early years as we began the wind energy research program. Shitao Ling and Eric Eggleston helped in the development of small wind turbine controllers for stand-alone water pumping and hybrid systems. In later years, Brian Vick, Adam Holman, and Byron Neal helped with turbine blade testing and the beginning of certification testing.

I express my gratitude to my wife Ann for her patience with me while I wrote this book, along with her willingness to travel the side roads of America looking at wind turbines, sometimes spending hours waiting until I finished visiting with manufacturers or turbine owners or operators.

CONTENTS

Harvesting the Wind

The energy in the wind was first used to power small boats. As man learned to control these crafts, he built larger boats with larger sails. In time, sails were placed on rotating booms to turn shafts and thus operate grinding stones and pumps. Archeological records have shown that early forms of windmills were used by the Babylonians, Chinese, and Egyptians. Written references to windmills are found in early manuscripts, with a Persian vertical-axis windmill described in some detail in the 7th century A.D. European documents after the 13th century refer to various windmill designs. European mills used rotors or sails constructed primarily of wood, reeds, and canvas prior to 1900. Many different concepts and designs were used, including springs and shutters to increase or decrease the sail area. Peak power from some of the larger mills reached 30 kW [1]. Figure I.1 shows a restored 18th-century Dutch windmill used to crush and grind seeds to produce vegetable oils.

Windmill development in the United States duplicated European designs, but American machines did not provide the flexibility needed to withstand the fickle weather of the Midwest. In 1857, Daniel Holladay

Figure I.1 Restored 18th-century Dutch windmill used for grinding grains. Others were used for pumping water.

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began making wind machines that were self-regulating using paddle-shaped blades that pivoted, or feathered, as wind speed increased. The Eclipse windmill was introduced a few years later and was the first to use a solid wheel assembly and a side vane to turn the rotor out of the wind as velocity increased. Both of these machines used a reciprocating pump driven by a crank or offset cam. Such wind machines worked sufficiently to lift water from deep underground sources in the arid parts of the United States. Enclosed gears, metal wheels, and towers improved until the systems operated well in light winds and ran smoothly. At the beginning of the 20th century, it is estimated that 200 U.S. companies were offering windmills for powering saws and shelling corn as well as pumping water. Figure I.2 shows some of these windmills, which have been restored and placed in a windmill museum in Texas.

Wind machines that generated electricity for charging batteries were being manufactured in the 1930s. They were much different from earlier multiple-blade water pumpers in that their two or three blades rotated at much higher speeds. Electrical output was normally 12, 24, 32, or 48 volts DC, and they incorporated batteries for energy storage. Most electric systems were capable of generating and storing enough power to operate two to three lights and a radio. The Jacobs Wind Electric Company reported selling tens of thousands of these units between 1931 and 1957 [2]. Most of the electric systems were discarded when the U.S. Rural Electrification Administration (REA) installed electric power lines in many farming and

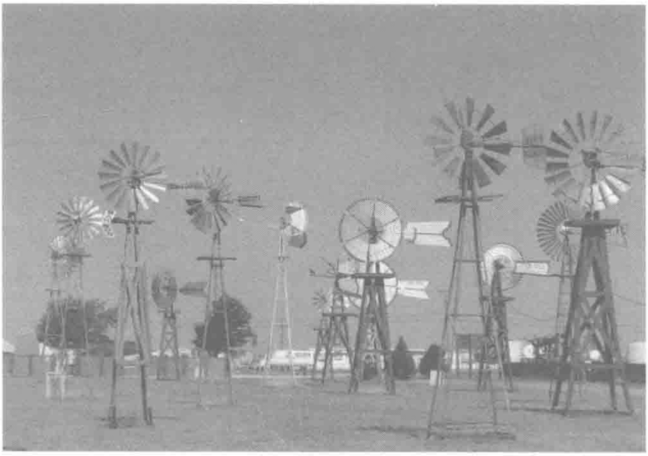

Figure I.2 Restored American windmills manufactured from 1875 until 1940 and used for water pumping. This basic design is still being manufactured.

ranching regions. However, water-pumping windmills never disappeared from the western United States because they were needed to provide water for livestock in remote areas.

During this time, several countries in Europe were experimenting with larger wind turbines that would generate electricity for connection to the electric grid. Almost all of these efforts were abandoned sometime in the 1960s because of the abundance of low-cost petroleum for fueling steam-electric plants. However, the 1973 oil embargo resulted in a desire to develop alternative energy sources, especially to generate electricity. Governments in Europe and the United States started development programs using new aerodynamic theories and manufacturing techniques to produce new wind machines. At the same time, wind enthusiasts began to restore old wind electric plants to be used for electric power generation. By 1984, some 8,000 new units were installed and had a combined generation capacity of 300 MW [2]. They were manufactured by over 60 companies. Many were installed in Denmark, Germany, and California. The European machines were typically three-bladed, up-wind machines with a rotor diameter of 15 m (50 ft). They had a power rating of approximately 65 kW. U.S. manufactures produced either two-bladed or three-bladed down-wind machines with rotor diameters ranging from 10 m (33 ft) to 17 m (56 ft). By 1990, rotor diameters had more than doubled in size and power ratings had quadrupled.

The focus of most government-sponsored research and development was on wholesale electricity to utility grids. Little public money was used to advance designs of small machines used for homeowners and businesses. In the United States, the Department of Energy and the Department of Agriculture jointly sponsored some development activities related to applications in rural and remote areas, but little effort was put into new wind machine design. European countries focused on developing systems for export to developing countries with no electric grid and concentrated on battery charging and water pumping.

Thus most new development has been supported and carried out by individual wind turbine manufacturers rather than government programs. Beginning in the mid-1990s, The Department of Energy funded some research and development through the National Renewable Energy Laboratory (NREL), but individual manufacturers still did most of the work. Table I.1 lists early manufacturers of small wind machines, some of which have survived the ever-changing marketing and regulatory environment. Many other manufacturers closed after producing only a few machines,

Table I.1 Examples of small wind turbines manufactured during the 1980s

Manufacturer	Model	Rotor diameter (m)	Rated power (kW)	Generator type
Aerolite	1200	7.0	12.5	Induction 120/240 AC
Aerowatt (France)	24 (other models up to 900 watts)	1.2	30 watts	12 volts DC
Bergey Windpower	1000	2.5	1.0	Permanent magnet alternator DC or AC
	Excel	7.0	10.0	
Dakota Wind & Sun		4.3	4.0	200 volts DC
Enertech	1500	4.0	1.5	Induction 120 AC
Jacobs Wind Energy Systems	10	7.1	10.0	Synchronous AC/DC
	15	7.4	15.0	Synchronous AC
	17.5	8.0	17.5	Synchronous AC
Marlec Engineering Company (UK)	Rutland 500	0.51	50 watts	12 volts DC
North Wind Power (Northern Power Systems)	HR2	5.0	2.2	Synchronous alternator with wound stator
Southwest (Wind Baron)	Windseeker	1.52	350 W	Permanent magnet alternator DC
Whirlwind	2012	3.4	2.0	120 volts DC
World Power Technologies	Whisper 600	2.1	600 Watts	Permanent magnet alternator DC or AC
	Whisper 1000	2.8	1.0	
	Whisper 3000	4.5	3.0	

mostly because of insufficient capital to finance the several iterations needed to create a successful product. Still others have been subject to sale or merger.

At least three major design changes have influenced the performance and reliability of small wind machines over the last 20 years. The switch from DC generators and small induction motors to permanent magnet alternators has significantly improved performance and extended lifetime operation (Figure I.3). Alternators can be built in small compact units that are lighter and can be easily fitted to a small tower. A second design change is in rotor blade materials and construction. The use of injection-molded blades provides a much more efficient airfoil and one with better strength properties to withstand extreme wind speeds and higher operating speeds (Figure I.4). Lastly, the inverters and power electronics available for small wind machines provide almost seamless integration with the electricity grid (Figure I.5). They provide systems that have almost 100% availability and perform real-time monitoring of the wind machine.

Although small wind turbines do not make up a large percentage of new generating capacity, they do account for more than a doubling of the number of medium and large turbines installed. In 2011 almost 7,500 small wind turbines were installed in the United States, with U. S. manufacturers exporting slightly more than 3,000 units [3]. Of the number of small wind turbines installed, only 4% were larger than 10 kW. A little more than 5,000

Figure I.3 The development of permanent magnet alternators has provided improved performance and reduced maintenance.