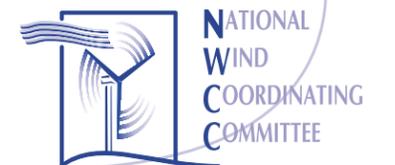
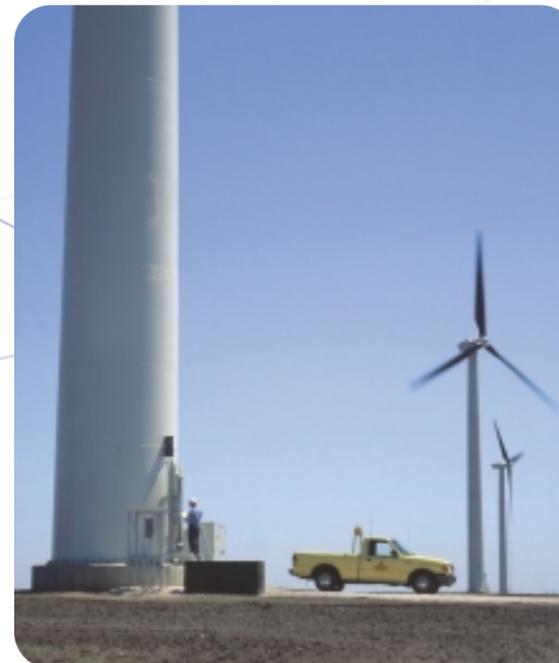


February 2001

Distributed Wind Power Assessment



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Cover Photos Courtesy of

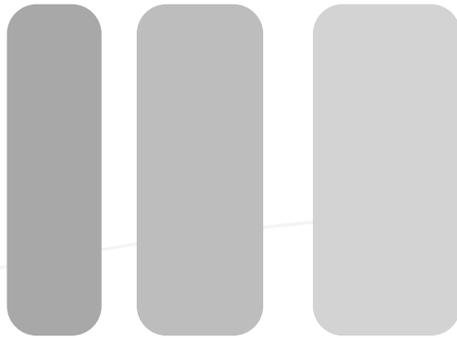
Thomas A. Wind, P.E., Wind Utility Consulting (top photo) and Lloyd Herziger, ©2000 Enron Wind (bottom photo). The top photo is a private cooperative-owned 3-turbine cluster on the Jensen farm in Denmark. The photo on the bottom is the 2.25-MW Algona, Iowa, distributed wind project jointly owned by seven utilities.

Special appreciation to Kevin Porter at NREL, Brenden Kirby at ORNL, Ed Holt, of Ed Holt and Associates, and Ronald Lehr for their comments and insights. The Principal investigator wishes to thank the NWCC Distributed Wind Working Group and the project management team of Brian Parsons at NREL, Ed DeMeo at EPRI and (currently) Renewable Energy Consulting Services, Inc., and Abby Arnold, Heather Rhoades-Weaver, Gabe Petlin, and Detra Stoddard at NWCC (through Resolve, Inc.) for their guidance, assistance, and understanding.

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No U.S. Department of Energy funds were used for the printing of this document.



February 2001 | Distributed Wind Power Assessment



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Prepared for the NWCC Distributed Wind Working Group

Preface

This assessment report is a product of the Distributed Wind Working Group of the National Wind Coordinating Committee (NWCC). The NWCC was formed in 1994 as a collaborative endeavor composed of representatives from diverse sectors including electric utilities and their support organizations, state utility commissions, state legislatures, environmental organizations, wind equipment suppliers and developers, green power marketers, consumer advocates, agriculture and economic development organizations, and local, regional, state, tribal and federal agencies. The NWCC identifies issues that affect the use of wind power, establishes dialogue among key stakeholders, and catalyzes activities to support the development of an environmentally, economically and politically sustainable commercial market for wind energy.

The NWCC Distributed Wind Working Group was formed to examine and assess distributed-wind development options in the United States. In addition to this document, the National Wind Coordinating Committee has many other wind-energy-related materials on its web site: www.nationalwind.org.

For comments on this assessment report or questions on distributed wind energy, contact the National Wind Coordinating Committee Senior Outreach Coordinator c/o RESOLVE, 1255 23rd Street NW, Suite 275, Washington, DC 20037; phone (888) 764-WIND, (202) 965-6398; fax (202) 338-1264; e-mail nwcc@resolv.org.

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Report Summary

Distributed generation could account for 20% or more of new generation coming on line in the next 10 to 12 years [Moore 1998]. Unlike large central-station generation, which is connected to the utility transmission system, distributed generation is typically smaller and connects to the grid at distribution-voltage levels. There is debate about the role wind power generation could play in the nation's expanding market for distributed generation because most wind power development in the United States has come from large-scale wind power plants, sometimes referred to as wind farms, and because wind-generated electricity is intermittent. Some wind power advocates postulate that distributed wind generation offers significant advantages over wind farms to utilities interested in adding wind generation.

The United States does have some limited experience with distributed wind applications. From the late 1920s through the early 1950s, thousands of small windmills and turbines were installed on farms all across the country to pump water and generate electricity. However, the Rural Electrification Administration (formed in 1936) helped create a centralized electricity grid, encouraging farmers to disconnect their turbines and join the system. This ultimately led to the demise of the U.S. wind turbine industry, as the main manufacturers went out of business in 1956 [Righter 1995].

Utilities in the United States have had little experience with adding a single wind turbine or small cluster of turbines to distribution lines at multiple locations. Such distributed installations typically have been less than 5 megawatts (MW) in the United States and Europe, and connect to power lines that directly serve residential, commercial, and small industrial customers. This power size limit is somewhat arbitrary, but is generally consistent with the technical constraints associated with integrating wind power for a large portion of the U.S. distribution system. The extent to which a wind project is integrated into the local economy is also a characteristic of distributed generation. A distributed wind installation may or may not be used to offset customer electricity consumption, depending on turbine ownership and the point of connection relative to the customer's meter.

At the request of the National Wind Coordinating Committee (NWCC), the authors undertook a comprehensive Distributed Wind Power Assessment to enhance understanding of business, policy, and technical issues associated with the deployment of wind-electric generating systems in the distributed-generation mode. The assessment evaluated distributed wind generation in Europe to determine what aspects of the European experience could apply to the deployment of distributed wind projects in the United States. It then identified the political, economic, and technical factors that would likely determine the long-range prospects for distributed wind generation in the United States. After conducting extensive interviews with experts in the field, original research, a comprehensive literature review, and in-depth analysis, the



Wind turbines, such as this 225-kW machine in Adair, Iowa, could play a role in the nation's expanding market for distributed generation. The turbine shown here provides electricity for Schaefer Systems, Inc., a plastics manufacturer. Photo courtesy of Vestas - American Wind Technology, Inc.

authors developed key conclusions regarding the progress and prospects for distributed wind generation in the United States.

Much of the focus of this report is on distributed markets for large wind turbines. Very few of the turbines in Denmark and Germany are in the range of tens-of-kilowatts that is associated with “small turbines.” Distributed wind projects in both countries are predominantly owned by entities that wish to take advantage of economies of scale from larger turbines: groups of investors, utilities, or farmers with relatively large operations and corresponding electricity loads. The market for small wind turbines in the United States is different in many ways from the distributed market for large turbines. Small wind turbines offer flexibility in their electrical output and can handle weak or voltage-limited distribution lines. Through the use of power electronics and permanent magnet alternators and/or synchronous generators, small wind turbines can produce either AC (single phase or three-phase) or DC electrical output with high power quality. Because of these characteristics, small wind turbines can be interconnected on the U.S. distribution system much more readily, i.e., without the same power quality or technical limitations, as larger turbines. In addition, there are financial incentives for small wind turbines in many states, e.g. net metering and buydown programs. Individual homeowners can install and maintain their own small wind turbines, dramatically affecting approaches and costs for project development, installation, and maintenance. Therefore, readers should not assume that statements made in this report are valid for small wind turbines, unless specifically noted.

SOME LESSONS FROM EUROPE APPLY TO THE UNITED STATES; OTHERS DO NOT

Parallels

There are parallels between market and policy conditions that existed when distributed wind deployment in Europe began and those in the United States today, including:

Distributed Wind Generation Is a Natural Investment for Farmers. In Europe, “wind farming” was an extension of what farmers were already familiar with—the development of land-based natural resources to sell on the open market. U.S. farmers are likely to see a similar connection.

Local Financing Is Critical. The involvement of local banks in financing new projects could be critical in assuring a significant role for distributed wind generation in the United States. After subsidies became available, Danish banks began offering flexible terms on loans for windfarming. If distributed generation becomes economical in this country, U.S. banks might also be inclined to assist farmers in improving the value of their land, particularly since the U.S. agricultural economy is weak (as was Europe’s during the early years of distributed wind generation growth).

Strong Industrial Bases Exist. Denmark and Germany both had strong industrial bases, equipment maintenance capabilities, and financial services expertise upon which to develop a new industry—circumstances that exist in the United States. Where there is money to be made in the United States, the infrastructure can quickly be built to support a new industry, particularly in the areas of manufacturing and finance.

Differences

The lessons learned from Germany and Denmark must be interpreted carefully in applying them to U.S. electric distribution systems. Key differences between the United States and those countries include:

Utility Market Structures. These may limit the degree of applicability of European experience in the United States. U.S. electricity prices are much closer to the cost of production than they historically have been in Denmark (because Denmark has higher taxes). Consequently, technical considerations, costs, and in limited cases, the ability to capture the value of distributed benefits, are expected to be far more influential in determining the course of development for distributed wind generation in the United States than they were in Europe.

Government Policy. In Germany and Denmark, government policies provide strong financial (especially mandated premium prices, known as feed-in tariffs) and non-financial incentives that facilitated distributed wind development by landowners and other private, local individuals. By contrast, U.S. federal policy has resulted primarily in development of large windfarms. A few U.S. states

have had limited success in stimulating distributed development through incentives. However, it should be noted that, at the same time that the United States considers the proper applications of small distributed projects European wind developments are moving toward larger project sizes.

System Electrical Characteristics. In Europe, single turbines and small clusters of turbines are connected to a relatively strong and robust distribution system consisting entirely of three-phase lines. These conditions are favorable to distributed interconnection, and are less common in the United States.

Interconnection Standards and Requirements. Standards and requirements for wind generation have been well defined and are fairly uniform in Denmark and Germany. They are neither well defined nor uniform in the United States.

Distribution System Upgrades. These were carried out, if needed, primarily at public expense in Germany and Denmark.

Land Area and Population Density. Both Denmark and Germany have relatively small land areas and high population densities whereas the United States is land-rich with comparatively few people. In Europe, developing distributed wind projects has been the preferred approach partly because land use issues limit the siting of large projects. Resource assessment, standardized siting and service, and installation were all aided by the fact that all distances are relatively short.

Cultural, Business, and Political Traditions. Denmark and Germany have a tradition of more national government influence (to different degrees) on industry and regional and local government. Early government pressure on utilities to establish premium buy-back tariffs and guarantee interconnection (before national legislation) helped jump-start the market in Denmark. In addition, permitting in both countries is fairly uniform due to more federal influence. U.S. business and political traditions place more emphasis on free markets, local permitting, lower taxation, and less government involvement in the market. Because Danish and German populations are smaller and more homogeneous than in the United States, public

consensus was able to affect dramatic national policies supporting wind energy, especially the feed-in tariffs. With a more heterogeneous population and many competing interest groups, it traditionally has been difficult to achieve such strong policy response in the United States based on public majority opinion.

Impact of Grass-Roots Support. Popular support for wind power grew in Denmark because of the 1970s oil shortages, which strongly impacted the economy and living conditions in that country. Germany's political commitment to wind development coalesced after the Chernobyl nuclear power plant accident in 1986. Wind advocates in both countries provided critical information to landowners, utilities, and other market participants. The free flow of information meant that prospective owners and lenders knew what to expect from wind technology before making an investment, which lowered the perceived risk of the transactions. Although operational data for distributed wind projects is scarce in the United States, an active advocacy community is working to provide assistance and information to U.S. stakeholders. Nonetheless, while similar environmental concerns were raised among the U.S. public to events such as Three Mile Island and the Oil Crisis in early and late 1970s, the U.S. policy response and market results were much different than in Denmark and Germany.

FEED-IN TARIFFS, OTHER FACTORS KEY TO EUROPEAN WIND MARKET DEVELOPMENT

Mandated premium prices for wind-generated electricity, known as feed-in tariffs, have been the major driver of new wind energy projects in Denmark and Germany in recent years. A feed-in tariff is the rate paid for electricity fed into the grid. The large (\$0.09-\$0.10/kWh in 1998) tariffs create acceptable financial returns and risk levels for wind projects. These payments are currently well above wholesale rates in both countries (85% of pre-tax retail rates in Germany, and over pre-tax retail rates in Denmark). Thus, in both countries, ratepayers are subsidizing wind power generators. In Germany, additional government production-based subsidies ended in 1995. In Denmark, payments to wind generators continue to include subsidies taken from taxes on sales of electricity from non-renewable sources of generation.

Feed-in tariffs offer several advantages as a policy tool. First, they can be used equally by all project owners, regardless of tax liability or income level. Secondly, they are easy to administer and exact minimal transaction costs. The feed-in tariff level required to make projects financially viable is highly dependent on the wind resource. Thus, large tariff subsidies are not a universal requirement for providing incentives for distributed wind power in locations with better wind resources. Setting effective tariff subsidy levels is dependent on the wind resource, the project's financial parameters and costs, and the financial thresholds required by project owners. Still, using feed-in tariffs as a subsidy results in electricity consumers paying more for wind generated energy than they might under some free market alternatives.

Other factors key to European wind market development include:

- government requirements and incentives for local ownership (which were key to public acceptance of a high density of projects on the landscape);
- capital grants;
- national and state energy production-based subsidies (additional to feed laws);
- approaches to subsidize or otherwise pay for interconnection and grid reinforcement costs;
- required open access to the grid;
- subsidized loans;
- tax breaks for turbine owners;
- important information-sharing activities (organizations provided owners and manufacturers with political clout and an infrastructure that assisted the market to move forward quickly once incentives were in place); and
- national government influence (which led to standard permitting and zoning requirements).

U.S. DISTRIBUTED WIND INDUSTRY/ MARKET INFRASTRUCTURE REQUIRES ENHANCEMENT, IF DISTRIBUTED WIND IS TO BE ENCOURAGED

The development of a U.S. market for distributed wind generation will require additions to an infrastructure that currently serves a wind industry based on large wind power plants. The dispersed nature of distributed installations has different implications for resource assessment, siting and permitting, financing needs, power purchase contracts, interconnection standards, U.S. manufacturing and service industries, and information dissemination to actual and prospective owners and the financial community. Experience in Europe has shown that it is useful to begin activities to build infrastructure in many of these areas prior to significant market activity. However, development of infrastructure for operation and maintenance (O&M), resource assessment, manufacturing, and financing will depend, to varying extents, on market volume and activity, and government policies and programs.

PUBLIC ACCEPTANCE OF WIND PROJECTS DEPENDS ON LOCAL FINANCIAL PARTICIPATION

Local financial participation is key to public acceptance and the largest possible market penetration because it enables benefits to accrue to the people who bear the localized costs of wind power, according to the majority of European experts interviewed. These experts report that local public perceptions are usually favorable if financial participation is present and often unfavorable if it is not. They believe that acceptable financial return is the most important key to local ownership. In Denmark, approximately 250,000 individuals, or 5% of the population, had an ownership stake in wind turbines by the end of 1997. On both sides of the Atlantic, local acceptance of wind power has been reported to increase or remain high after projects have been installed. Several other factors can positively affect public acceptance:

- environmental benefits contribute to a sense of local pride;
- local economic benefits (which are maximized with local ownership) are significant; and

- tourism draw can also generate local economic benefits and enhance local image.

DISTRIBUTED WIND-SPECIFIC ISSUES COMPLICATE UNCERTAIN, EVOLVING REGULATORY AND MARKET ARENAS

Restructuring of the electricity industry is proceeding at different rates throughout the country, making the effort to define the benefits and challenges of distributed wind generation that much more difficult. Some states are fully engaged in unbundling electric utility services, while others have eschewed the process entirely. Although it is likely there will eventually be federal restructuring legislation, it is not clear when this will happen or what form this legislation will take. Rather than having a single set of well-defined rules and relationships, the market of the future will be composed of a plethora of mechanisms and customer relationships for transaction of new products and services that could make distributed wind power more valuable. Such transactions will require market-based price signals. These changing market conditions will create challenges for all supply resources. Depending on the outcome of market restructuring, there could be either enhanced or diminished opportunities for distributed wind generation.

General Issues

There are questions about how distributed generation will be valued and regulated in the future. The European approach of simply sweeping away all valuation issues by generously subsidizing wind projects and distribution system reinforcement costs is not likely to occur in the United States. Rather, individual states (and eventually the federal government) will undertake the Herculean task of developing a new regulatory and market paradigm for distributed generation in general. A primary challenge in all states, whether they have restructured markets or not, will be to create regulations that are consistent with, and encourage the fair allocation of, costs or benefits associated with distributed generation. For distributed generation owned by either independent power producers, who qualify under the Public Utilities Regulatory Policies Act (PURPA), or regulated utilities, the regulatory paradigm developed in the 1980s uses a utility's avoided cost of providing electricity as the basis for valuing generation additions, either central or distributed. Only generation costs are

typically included in avoided cost estimates because distribution, transmission, and ancillary service costs associated with being connected to the grid are considered relatively fixed. Avoided generation costs measure capacity and energy benefits of distributed generation in a traditional, regulated return-on-equity, or "required revenues" framework. Because it bases the value of distributed generation on utility cost of (generation) service, this paradigm will not meet the needs of future competitive electricity markets. Further, the paradigm is not appropriate for a vertically integrated utility that employs a separate business strategy for its distribution functions.

Establishing a new regulatory system that moves beyond this outdated approach will not be easy. The new system will require economic accounting approach(es) based on allocations of current asset classes to distribution system functions, followed by a pricing approach that reveals the incremental costs of serving customers to all market participants. Such a pricing approach would enable distributed resources to be deployed in the locations where they are most valuable. If the goal of public policy is to encourage end users to own distributed generation, lawmakers and regulators will have to create new incentives for utilities and customers to accomplish this, in addition to developing accounting and pricing approaches. If a regulatory system can ensure that open access is the most profitable approach for a utility's network business, then there would be opportunities for distributed generators to connect to the grid.

Several new regulatory approaches to align utilities' profit motive with the deployment of distributed resources have been suggested. They include:

- basing utility performance on a least cost provision of distribution, i.e., the lowest cost investment that would allow a distribution utility to meet its requirements;
- determining a least cost method for meeting customer needs; and
- combining use of performance-based rate making (PBR) using revenue caps as a regulatory framework, and geographically de-averaged buyback rates to create price signals with incentives to both utilities and customers.

Wind-Specific Issues

Certain characteristics of distributed wind generation will complicate efforts to establish new regulatory approaches. These characteristics include:

Valuation and Accounting of Distributed Benefits. The intermittent nature of the wind resource limits the existence of distributed system benefits from wind generation. Further, because of this intermittency, the valuation of non-energy distributed benefits is more difficult and costly for wind than for most sources of distributed generation. In addition, benefits from wind generation, when they are positive, will tend to be less than for other generation sources. There is a wide range of opinions on the extent to which, an economically-feasible regulatory system can be developed to enable widespread evaluation and subsequent accounting and market pricing of distributed costs and benefits from wind generators. One thing that is clear is that the European approach of simply sweeping away all valuation issues by generously subsidizing wind projects is not likely to occur in the United States.

Environmental Benefits. Wind environmental benefits are real, but they tend to be undervalued or not valued at all. Should they be calculated and accounted for, and if so, how? Credit trading systems are under consideration, but care will be required to ensure that smaller, distributed plants are accounted for. In addition, can local environmental benefits be quantified relative to those that accrue from larger, distant wind power plants?

Costs or Benefits of Ancillary or Other Services. If transmission and distribution charges for rural areas, which are usually more expensive to serve, are unbundled as a result of restructuring, the impact on the value of distributed wind projects could vary widely. In general, geographic de-averaging of costs and rates would benefit distributed generators with respect to central station plants. However, it may be that the majority of distributed wind sites would incur disproportionate costs compared to other distributed generators for non-energy services required by the wind plant.

Distribution Wheeling Charges. These charges could eliminate the economic value of wheeling power out of the distribution system at low

load periods, which, because of the intermittent wind resource, could be a disproportionately higher source of revenue for wind projects compared to other distributed generation sources. The end result would be a decrease in the value of distributed wind compared to those other sources.

DISTRIBUTED WIND GENERATION BENEFITS WILL OFTEN BE LIMITED

The interconnection of substantial amounts of wind generation to U.S. electric distribution systems is technically feasible. In very limited instances, the addition of a single turbine or small cluster of turbines at a specific location with an excellent match between wind resource and system load could delay or eliminate the addition of distribution facilities, reduce losses, serve additional loads, and provide voltage support on weak distribution lines. More often, however, wind will only provide modest-to-no system benefits and may require reinforcements to the distribution grid. Therefore, distribution system benefits will usually provide minimal or no incentive to support distributed wind generation. In Germany and Denmark, potential distribution system benefits are almost never evaluated or considered, because these benefits are typically small and are not needed as justification for adding wind generation. Correspondingly, the Germans and Danes developed guidelines and design standards to address interconnection issues without the need for detailed, costly individual project studies.

From the utility perspective, distributed wind turbines present a challenge because the power produced by them is intermittent. Distributed benefits depend on the time correlation between the wind generation and the load. Utilities can estimate benefit size by using a probabilistic approach similar to that used for other distribution-reliability design standards. In addition, because of a wind turbine's intermittent and fluctuating power output, large wind turbines (over 500-kW) can cause more power quality problems on the distribution system than other distributed generation. At present, a utility engineer must evaluate each proposed installation of one or more large turbines to determine whether power quality impacts would be acceptable.

In addition to the correlation between the wind generation and load, the extent to which one or

more benefits can be realized at a given location depends upon a number of other factors:

- turbine design, size, and location on the distribution system;
- wind resource characteristics;
- characteristics of the subtransmission and distribution systems and loads near the proposed wind site;
- transmission system characteristics, in particular reliability criteria and loading levels;
- generation system characteristics, including generator types, installed capacity, native load shape, and growth; and
- ownership of turbines, generation, transmission, and distribution systems (i.e., vertically integrated utility, distribution utility, utility customer, regulated versus unregulated power company).

The authors conducted a case study in a typical area of the Midwest to investigate the potential for adding distributed wind power at different levels of grid reinforcement. The study uses actual information and data from a 1942-square kilometer (750 square mile) area in Iowa. After plotting all power lines and distribution system equipment in the region, a preliminary engineering analysis was made to determine the maximum number of 750-kW wind turbines that could be installed on the existing distribution systems in the area with three different levels of distribution system reinforcement. The study found that distributed wind capacity could be tripled by adding reinforcements to the local distribution system at an average cost of about \$60/kW. The study also identified an area of load growth as a key site for further investigation of potential distributed benefits.

COST OF EVALUATING “DISTRIBUTED BENEFITS” FROM WIND PROJECTS IS A BARRIER TO THEIR IDENTIFICATION

The cost associated with the analytic process described above is an additional and perhaps even more critical barrier to the ability to obtain value for distributed benefits (when they exist) from wind projects. This cost is inherently higher for distributed wind projects than for projects that produce firm (non-intermittent) power and may be prohibi-

tive for most project owners and developers unless simplified evaluation approaches can be developed. Simplified methods to identify locations in the distribution system where generation value is potentially highest are currently being examined by the distributed generation community. This will help to screen applications where total cost can be minimized, but the question of specifically quantifying benefits and passing the value on to the wind generation owner remains problematic.

GRID CHARACTERISTICS AND POWER QUALITY LIMIT DISTRIBUTED WIND SITES IN THE UNITED STATES

The most important consideration for adding wind turbines to a distribution system is the electrical strength or stiffness of the distribution system at the proposed point of interconnection. Strength refers to the ability to deliver or absorb power. The requirements, benefits, and penetration limitations of distributed wind generation depend on whether a specific project is connected to a strong, thermally limited distribution system or a weak, voltage-limited distribution system. A strong distribution system can absorb significant amounts of intermittent wind generation with relatively modest impacts on the quality of power. Most rural distribution systems in the United States are weak, voltage-limited systems.

Single turbines and small clusters of turbines in Europe are connected to a relatively strong and robust distribution system consisting entirely of three-phase lines. These strong distribution systems were an important factor for distributed wind development. Circumstances are different in the United States. If only minimal upgrades are required for turbines to be added to the distribution system, then adding wind generation to a U.S. distribution system may be less expensive than adding it to a transmission system. However, the majority of distribution lines in rural areas, which are most suitable for wind generation, are single phase and would require upgrading to three phase to connect wind turbines rated at more than 20 kW. Nevertheless, distributed wind generation could be limited to areas with existing three-phase lines within a few miles of the substation and still achieve substantial penetration in certain rural areas of the United States.

The installation of significant amounts of distributed wind generation is expected to have substantial

power quality and loading impacts on local utility distribution systems and subtransmission facilities connected to distribution substations. These impacts will be encountered at the distribution level long before the local wind penetration reaches a level that seriously affects a utility's transmission facilities. Distributed wind generation can often be connected to rural distribution lines in an amount about equal to the substation transformer capacity, assuming it is within a few miles of the substation and there is no other distributed generation. If power quality impacts are too high, or if the penetration level of wind turbines exceeds the allowed peak-load levels on the substations, then distribution system reinforcements could be required.

INTERCONNECTION STANDARDS BENEFIT MANUFACTURERS, UTILITIES, AND OWNERS

Utilities have the responsibility of maintaining a safe and reliable system and power quality. For this reason, individual utilities must have interconnection requirements for wind turbines (and other distributed generators). However, the requirements have not been standardized and vary according to the size of the generator. Because of a wind turbine's intermittent and fluctuating power output, it can cause more power quality problems on the distribution system than other distributed generation. Because of their size, wind turbines smaller than 100 kW are less likely to cause power quality problems in most distributed applications. Thus, interconnection requirements for these turbines could be very simple. However, larger wind turbines can cause power quality problems on a distribution system, particularly if the turbines use constant-speed generators without soft starting power electronics. At present, because manufacturing design standards and certification do not exist, utility engineers must perform detailed evaluation of each proposed installation of large turbines to determine whether power quality impacts would be acceptable. In conjunction with standards, simplified evaluation procedures, but not any single or required approach, could reduce the costs for evaluation of interconnection requirements and impacts.

Manufacturers, utilities, and turbine owners would all benefit from the interconnection standard currently proposed by the IEEE Standards Coordinating Committee. Manufacturers could use it with an application guide to design a wind turbine's

electrical interface equipment. With a certified turbine design, the utility's interconnection evaluation process would be simpler and less expensive. Owners would use a simple standardized application form for interconnection that would provide all of the information needed by the utility. In general, the more sophisticated turbines and controls reduce the impact on power quality, and continued reductions are expected with better turbine designs. These improvements will enable more wind capacity to be installed on distribution systems. The trend toward larger wind turbines, however, will exacerbate power quality impacts if they are connected to the distribution system. The net effect on any system will depend on the number and type of turbines connected.

INFRASTRUCTURE AND VOLUME ARE KEY TO COST REDUCTION

There is no inherent reason why costs cannot be reduced if demand for distributed wind generation grows. Government policies and incentives as well as changes in market infrastructure would make a significant difference. Desirable infrastructure developments would provide individuals and organizations with information and expertise in resource assessment, project development, wind technology, bulk purchases, financing, and operations and maintenance. Without these, capital and O&M costs for most distributed projects are likely to remain well above those for large wind farms. Prior to significant market volume, there are various strategies that could be considered to potentially make distributed wind a better investment, including:

- use of larger turbines;
- concentration of early development in a few geographic areas;
- aggregation of purchases;
- comparison of cost of clusters versus single turbines;
- use of existing infrastructure such as access roads, grid connections, or substations; and
- utilization of "sweat equity" by landowners.

The U.S. market experience with turbine manufacturing and project development and operation for

large wind plants could speed up the development of an infrastructure to support distributed wind generation. However, infrastructure development may not proceed quite as smoothly as in Denmark, which had excess industrial capacity and a better vocational training system for O&M technicians in their early market period. Because the United States has a huge land area in comparison to Denmark and Germany, it is more economical in terms of energy production and O&M costs to concentrate wind generation in large installations unless there are enough distributed projects within an area to efficiently use labor. The wider range of resource levels in the United States can also make it economically attractive to concentrate projects in better resource areas. The basic approaches to wind data collection are the same for distributed projects and wind farms. None the less, the larger area and more complex terrain makes resource assessments for distributed projects more expensive than for U.S. wind farms and Danish and German projects on a per-MW basis. Government support for improved development of, and public access to, wind resource assessment information, tools, and data sets could help reduce costs somewhat for smaller projects. However, there are limits to how much assessment costs can be curtailed if the process continues to require field measurements.

PRECURSORS FOR MARKET SUCCESS

Many actions can be taken to establish precursors needed for a dynamic distributed wind market before such a market is fully in place. Such actions are discussed in the report and include development of:

- information and technical assistance to utilities, landowners, and the financial community;
- viable ownership models for landowners;
- standard power purchase agreements;
- standard permitting and zoning requirements;
- design and interconnection standards;
- simplified technical evaluation procedures (not one single or required approach) for determining interconnection requirements and impacts; and

- affordable and accurate wind resource assessment.

There are other market precursors that will be more difficult to establish because they either require market volume or regulatory/policy actions. These include:

- stable cashflow and acceptable economic returns;
- new regulatory and market system that establishes
 - economic accounting approach(es) based on distribution system functions rather than on asset classes (many feel this is less important because they doubt whether evaluation of distributed benefits will become cost effective for wind installations);
 - open access to the distribution system grid for customer-owned generation; and
 - market-based pricing incentives (instead of cost-based) for customers and utilities
- available financing at affordable terms; and
- lower project and O&M costs.

Chapter 1 – Introduction

Distributed generation could account for 20% or more of new generation coming on line in the United States in the next 10 to 12 years [Moore 1998]. Unlike large central station generation, which connects directly to the utility transmission system, distributed generation is typically smaller in size and connects to the grid at the distribution voltage level. Because wind power generation has heretofore occurred primarily in large wind power plants, there is debate about the role it could play in the nation's expanding market for distributed generation. At the request of the National Wind Coordinating Committee (NWCC), the authors undertook a comprehensive Distributed Wind Power Assessment to enhance understanding of business, policy, and technical issues associated with the deployment of wind-electric generating systems in the distributed-generation mode.

Although each location on the electricity grid has its own characteristics, there are likely to be many locations where wind turbines of appropriate size and technical characteristics can be added to the grid at the distribution level. This assessment revealed that, in addition to providing real and reactive power to distribution lines, distributed wind generation could provide transmission and distribution (T&D) support, peak shaving, substation capacity deferral, and power quality support (other than providing reactive power) in limited circumstances. There may also be circumstances where distributed wind turbines are more attractive than larger windfarms for marketing wind's environmental benefits through "green pricing" or "green marketing" programs.

From an electrical system point of view, there are sites where distributed connection can make economic sense, assuming the evaluation of system impacts and benefits can be assessed in a cost effective manner. However, unlike many emerging distributed generation technologies, the intermittent nature of wind means that its ability to deliver many of the non-energy distribution or transmission system benefits is affected by the degree of coincidence between turbine output and local load. Therefore, such benefits are limited to special cases where this coincidence is high. In addition, because the evaluation of such potential benefits is more difficult and costly for distributed wind

generators, it is likely that such evaluation may be economically prohibitive for most projects unless simplified evaluation procedures, i.e., not any single or required approach, can be developed. Also, there is a wide range of opinions as to what extent an economically-feasible regulatory system can be developed to enable widespread evaluation and subsequent accounting and market pricing of distributed costs and benefits, when they exist, from wind generators. For these reasons, many feel that the role of non-energy distribution system benefits in increasing the opportunities for wind power may be quite small.



Figure: 1.1 Schaefer Systems 225-kW Turbine. Wind turbines, such as this 225-kW machine in Adair, Iowa, could play a role in the nation's expanding market for distributed generation. The turbine shown here provides electricity for Schaefer Systems, Inc., a plastics manufacturer. Photo courtesy of Vestas - American Wind Technology, Inc.

REPORT OBJECTIVES

Denmark and Germany have already achieved substantial market penetration with distributed wind systems. This report will examine the European experience, discuss the similarities and differences between Europe and the United States, and highlight useful lessons learned in Europe. It will explore the prospects for deploying significant amounts of distributed wind power in the United States. It will also examine the economic and technical issues facing utilities and land owners interested in adding distributed wind generation, identify the challenges of deploying small clusters of wind turbines on a distribution system, and describe opportunities for encouraging the development of distributed wind power in the United States. The report has the following primary objectives:

- Provide information to serve as a common foundation of knowledge for the National Wind Coordinating Committee and others to understand and discuss issues associated with the adoption of distributed wind power;
- Delineate the benefits, costs, and technical requirements associated with developing distributed wind projects;
- Characterize the policy drivers and market, industrial, and social characteristics that fostered European distributed wind development and contrast these attributes with the current U.S. market and policy climate; and
- Describe where distributed wind may be either constrained or encouraged by market, institutional, or regulatory factors.

The report has the following secondary objectives:

- Identify attractive combinations of economic, technical, and social characteristics for distributed wind applications in the United States;
- Provide information required to identify specific opportunities for distributed wind systems on a preliminary feasibility level; and
- Describe technical options that can enhance the value of distributed wind projects.

DEFINITION OF DISTRIBUTED WIND POWER

Most wind power development in the United States has favored large-scale wind power plants, sometimes referred to as wind farms. U.S. utilities have had little experience with adding a single wind turbine or small cluster of turbines to distribution lines. There was a total of approximately 5 to 10 megawatts (MW) of large turbines with such connections by the end of 1999. This report defines distributed wind power installations as typically less than 5 MW in size and connected to power lines that directly serve residential, commercial and small industrial customers. Larger wind power installations with the same interconnection characteristics are possible from the integration standpoint, but since there is a much more limited number of such sites, they are only a small percentage of the potential distributed market for wind. The extent to which a wind project is integrated into the local economy is also a characteristic of distributed generation. A distributed wind installation may or may not be used to offset customer electricity consumption, depending on turbine ownership and the point of connection relative to the customer's meter.

SMALL WIND TURBINES

Much of the focus of this report is on distributed markets for large wind turbines. Very few of the turbines included in the European markets studied for this report were in the range of tens-of-kilowatts that is associated with "small turbines." Although the Danish wind power market began with small turbines (average size of 11 kW in 1979), the market quickly evolved to the use of much larger, utility grade turbines (average size of 560 kW in 1997). By the time the German market began to accelerate in 1990, larger turbines were already proven in the marketplace and constituted the vast majority of installed units (average installed size in Germany in 1990 was about 150 kW, and over 80% of turbines had diameters of 16 meters or greater). Distributed projects in both countries are predominantly owned by groups of investors, utilities, or farmers with a relatively large operations and corresponding electricity loads.

The market for small wind turbines in the United States is different in many ways from the distributed market for large turbines. Small wind turbines offer flexibility in their electrical output and can handle

weak or voltage-limited distribution lines. Through the use of power electronics and permanent magnet alternators and/or synchronous generators, small wind turbines can produce either AC (single phase or 3-phase) or DC electrical output with high power quality. Because of these characteristics, small wind turbines can be interconnected on the U.S. distribution system much more readily than larger turbines, i.e., without the same technical or power quality limitations. In addition, there are financial incentives for small wind turbines in many states (e.g. net metering and buydown markets) and individual homeowners can install and maintain their own small wind turbines, dramatically affecting approaches and costs for project development, installation, and maintenance. Therefore, the reader should not assume that statements made in this report are valid for small wind turbines, unless specifically noted.

QUESTIONS ABOUT DISTRIBUTED WIND POWER

Because distributed wind generation differs markedly from large wind power plants, some wind power advocates have postulated that it offers significant advantages to utilities interested in adding wind power generation. The information in this report can be used to evaluate these claims by answering such questions as:

- Do distributed projects offer an alternative that fits better with the land ownership characteristics in the Midwest where it can be difficult for single entities to develop large tracts of contiguous land with good transmission access?
- Can existing transmission and distribution lines integrate more capacity from distributed wind generators than from large wind farms?
- Does geographic dispersion increase generation reliability of distributed wind projects compared to an equivalent amount of centralized wind power?
- Do distributed wind projects increase local economic development?

INTENDED AUDIENCE

This report is intended for a wide range of readers, including utility planners and engineers, policy

makers and advocates, public utility commissioners, state legislators, government agency staff, private landowners, and wind industry members. It is a summary of research conducted under a joint project for the National Wind Coordinating Committee and the National Renewable Energy Laboratory. New research includes (1) an analysis of European experience and its applicability to the United States; (2) a description of conditions, factors, and participant roles needed to encourage distributed wind deployment in the United States; (3) descriptions of technical requirements for, and issues associated with, interconnection and power quality; (4) an analysis of grid integration issues using a case study of a rural area in Iowa; (5) the development information for identifying potential sites where distributed wind may be able to capture additional transmission and distribution (T&D) system benefits; (6) the compilation and synthesis of cost data from Europe and the United States; and (7) a discussion of regulatory issues specific to distributed wind power. The report also synthesizes existing information in several areas where significant work has already been performed. These areas include (1) an overview of local economic development issues and a synthesis of available data and studies; (2) a description of potential T&D system benefits and the conditions required to attain them; and (3) a synthesis of challenges to deploying distributed wind generation.

HOW TO USE THIS REPORT

The research upon which this report is based is detailed in four technical appendices, which serve as reference materials. Because of the level of detail, these appendices have been reviewed by experts in the related disciplines rather than by the full NWCC.

This report contains three technical chapters. These chapters begin by listing the objectives and key questions that will be addressed. Each chapter is based on an unpublished, detailed technical appendix, which is available to readers desiring to understand the data and assumptions underpinning the chapters. For instance, the appendix to Chapter 3 contains a detailed discussion of a case study of the interconnection potential for distributed wind power in a typical region in Iowa, and detailed electrical diagrams and discussions to help engineers or other analysts understand siting limitations and tradeoffs.

Chapter 2 uses information from European and U.S. markets to analyze prospects and issues in the

United States concerning market and policy considerations, project ownership and its impact on local economies, the financial issues surrounding distributed generation, and issues related to infrastructure such as turbine manufacturing and wind resource assessment. The chapter is useful for those wishing to understand the non-technical reasons why distributed systems have been successfully installed in Europe and the lessons applicable to distributed generation in the United States. Policy makers, potential project owners, landowners, environmentalists, and market participants will all find information of interest in this chapter.

Chapter 3 addresses utility issues, in particular the regulatory and technical challenges and opportunities of distributed wind generation. It also addresses the identification and valuation of non-energy benefits of distributed wind power. This chapter will be of heightened interest to the regulatory and utility communities, consulting engineers, hardware manufacturers, and others wishing to understand these issues. The chapter is also useful to analysts and other readers who are interested in the identification of potential sites for integration of wind turbines into U.S. distribution systems, as well as in the evaluation of related technical issues.

Chapter 4 presents cost data for distributed wind systems in Europe and the United States. Policy makers, analysts, market participants, and others requiring an understanding of total project costs, cost elements, and strategies for cost reduction will find this chapter useful.

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Chapter 2 – Progress and Prospects

During the 1990s, markets for distributed wind generation flourished in Denmark and Germany. These countries were so successful in introducing wind technology into their utility systems that the European Union surpassed the United States in total wind power generating capacity by 1995. The following year, wind development in the United States, whose policies favored large-scale wind power plants, came to a virtual standstill. At the end of the decade, U.S. markets were once again growing, but considerably more unevenly than in Europe. However, it should be noted that, at the same time that the United States considers the proper applications of small distributed projects, European wind developments are moving toward larger project sizes. The contrast in the size, stability and characteristics of wind energy markets in the United States and Europe raises the following questions: (1) Might there be a role for distributed wind generation in the United States? (2) What lessons might be gleaned from studying the evolution of wind generation in Europe? This chapter will attempt to answer these questions.

When favorable developments in European industrial and market infrastructure were coupled with policy incentives in Germany and Denmark, a vibrant market for distributed wind power emerged. Mandated premium prices for wind-generated electricity, known as feed-in tariffs, were the primary driver of Europe's rapid wind market development. Strategies to ensure utility cooperation in

Chapter Objectives

Provide detailed information from European experience with distributed wind market models to gain insights that may facilitate opportunities for distributed applications in the United States. Evaluate factors or circumstances that need to be present in a local or regional wind market to support distributed wind development. Assess the role that wind development plays in the local economies where distributed projects are common. Compare economic benefits from locally owned distributed installations to large wind farm development. Evaluate the roles of various market stakeholders.

Key Questions Addressed in This Chapter

- What were the economic conditions, utility or government policies, and social characteristics or factors that led to the establishment of the infrastructure that currently supports the distributed wind market in Europe?
- What insights can be derived from the experience with wind cluster development in Denmark and Germany?
- Based on experiences in Denmark and Germany, what are essential local, regional, or national conditions ("precursors") for distributed project proliferation?
- Drawing on European and U.S. project experience, what are the important considerations associated with local perceptions, preferences, and needs?
- What are the key project ownership models and financial approaches?
- What are the mechanisms by which a wind project can contribute to the local economy? What secondary benefits do these contributions induce in the community?
- What studies have been performed, both in the United States and in Europe, either to provide data for use in the evaluation or to actually project local economic benefits?
- How do the benefits from locally owned projects compare to those from non-locally owned projects? Does project size play an important role in determining those benefits?
- What are the challenges to adoption of distributed wind, i.e., where is distributed wind constrained or encouraged by market, institutional, or regulatory factors?
- What must various market and policy participants do to encourage proliferation of distributed wind power?

connecting wind technology to the grid, additional incentives and subsidies, policy support for local ownership, cooperation among turbine owners and manufacturers, and successful public information exchange also played key roles in wind market development. Europe's financial community helped market development by creating flexible standard procedures that helped reduce wind's perceived risks and lower market transaction costs. As a result of these factors, Denmark had more than 1,700 MW of installed capacity and Germany had more than 4,400 at the end of 1999. The majority was new capacity installed at the distribution system level. Wind turbines produced about 10% and 2% of the total national generation for each country, respectively. Annual penetration of energy on the grid reached over 12% in one German state in 1998, and about 100% in a Danish municipality.

In Denmark, the accomplishments by 1999 were the result of more than two decades of incremental policy development that began with the oil crises of the 1970s. For Germany, the push to deploy wind generation began after the Chernobyl accident in 1986. Many of the insights concerning prospects for distributed wind generation in the United States come from the ways in which Denmark and Germany laid the groundwork for their robust wind markets.

This chapter begins with a short history of distributed wind development in Germany and Denmark and discusses the parallels between the United States, which is just beginning to consider distributed wind generation, and the early years in Denmark and Germany. It highlights national policies (and subsidies) promulgated in the 1980s and 1990s that put wind deployment on the fast track in Europe and discusses the changes in infrastructure, strategies for gaining public acceptance, and financing approaches that helped build European wind markets. The chapter then provides an overview of economic issues likely to shape U.S. distributed wind markets and how they differ from those in Europe. The chapter then discusses U.S. policy and incentives that have an impact on distributed wind generation. It concludes by presenting ways in which the U.S. industrial and agricultural infrastructure could support significant deployment of distributed wind generation.

THE EUROPEAN EXPERIENCE

Parallels Between Conditions in Europe and the United States

There are parallels between market and policy conditions at the beginning of distributed wind deployment in Denmark in the late 1970s and Germany in the late 1980s with those in the United States today, as shown in Figure 2.1 for Denmark. First, distributed wind generation was a good fit as an investment for farmers in Europe. Investing in wind generation was a natural extension of what farmers were already familiar with—the development of land-based natural resources to sell on the open market. In addition, land use regulations in Germany resulted in farm land being the easiest place to site wind turbines. Even before government incentives were in place, Danish and German farmers began investing in wind turbines. After subsidies became available, Danish banks began offering flexible terms on loans for “electricity farming.” If distributed generation can be shown to be economical in this country, U.S. banks might also be inclined to assist farmers in capturing the value of their land, particularly since the U.S. agricultural economy is weak (as was Europe's during the early years of distributed wind generation growth). The involvement of local banks in financing new projects could be critical in assuring a role for distributed wind generation in the United States.

- Wind energy “fit” as an investment for farmers
- Economic need because of a weak rural economy
- Excess industrial and service sector capacity
- Active grass-roots support

Figure 2.1 Early market conditions in Denmark.

Local financial participation is key to public acceptance and the largest possible market pen-

eration because it enables benefits to accrue to the people that bear the localized costs of wind power, according to the majority of European experts interviewed for this paper. These experts report that local public perceptions are usually favorable if financial participation is present, and often unfavorable if it is not. They believe that acceptable financial return is the most important key to local ownership. Fortunately, local acceptance of wind power tends to increase or remain high after projects have been installed on both sides of the Atlantic [Zimmerman 1998; Holt 1997; BTM 1998; AWEA January 26, 1998]. Other factors, such as wind's positive environmental benefits or tourism draw, can also positively affect public perception.

Second, Denmark and Germany both had strong industrial bases, equipment maintenance capabilities, and financial services expertise upon which to develop a new industry—circumstances that exist in the United States. Turbine manufacturing capability, particularly in Denmark, got a big boost not only from the new interest in distributed wind generation but also from sales to large wind power plant developers in California during the 1980s. As soon as domestic markets appeared, manufacturers responded to meet both the demand for turbines and for operations and maintenance (O&M). In addition, as soon as acceptable financial returns were possible, the wind industry drew workers from other industries and from a pool of skilled labor, which was available because of a weak economy. As these developments occurred, financial institutions began to perceive cash flow as low risk and rapidly developed the necessary products and processes to support the new industry. Then, as now, a stable cash flow stream was the most important criterion for obtaining financing.

Like Denmark and Germany, the United States has a dynamic economy. Where there is money to be made, the infrastructure can quickly be built to support a new industry, particularly in the areas of manufacturing and finance. The growth of service industries to support distributed wind generation is a more difficult matter, however. Because the United States has a huge land area in comparison to Denmark and Germany, it is more economical in terms of O&M costs to concentrate wind generation in large installations. The exception would be a rural area with a high enough concentration of distributed

wind projects to employ one or more windsmiths full time. The key is to use skilled labor fully and to reduce travel costs. In an early market, U.S. companies might find it profitable to expand into turbine O&M in a state (or multi-state region) with many distributed wind installations in relatively close proximity to each other.

Finally, there was active grass-roots support for distributed wind market development in Europe. The Danes have a cultural affinity towards wind power, and popular support for it grew because of the 1970s oil shortages, which strongly impacted their country. Germany's political commitment to wind development coalesced after the Chernobyl nuclear power plant accident in 1986. The Green Party's ideas, in particular, helped inspire public support for wind power development. While similar environmental concerns were raised among the U.S. public to events such as Three Mile Island and the Oil Crisis in early and late 1970s, the U.S. policy response and market results were much different than in Denmark and Germany. In conjunction with government incentives, wind advocates in those European countries provided critical information to landowners, utilities, and other market participants. Members of the public had ready access to wind resource data. Organizations of turbine owners kept detailed logs of O&M data on domestic turbines. Track records for specific machines and manufacturers' responses to problems were publicly identified, which put pressure on manufacturers to develop reliable machines. In addition, owners used the information to put pressure on politicians and influence government research and development activities. Manufacturers also worked closely with government to define national R&D priorities concentrated on developing reliable technology that would be accepted in the market. The free flow of information meant that prospective owners and lenders knew what to expect from wind technology before making an investment, which lowered the perceived risk of the transactions. Although operational data for distributed projects is scarce in the United States, an active advocacy community is working to provide assistance and information on distributed wind generation to U.S. stakeholders.

A Danish Wind Cooperative: A Case Study

Arne Jensen is a successful farmer in Ringkøbing County, in the far western part of Denmark. He has two turbines on his land. A third turbine, located on a neighbor's property, is part of the same cluster. Jensen is president of a cooperative that owns one of the turbines, a 750-kW Micon machine. Jensen chose the Micon turbine because it would give the best performance with the wind resource at his site. He originally wanted to invest in the whole turbine himself, but his wife felt that it might be too large a burden because they were near retirement.

Jensen secured financing and purchased the turbine on his own before establishing the cooperative. He felt he would be able to obtain better financial returns on his own as well as keep control of the project by developing it himself. As a result, Jensen saved the cooperative more than \$130,000 in developer fees. He also cleverly figured out a way to get into the deal with no money down. Another individual wanted to place a turbine on Jensen's land. So Jensen collected a royalty of \$23,100 (DKK150,000) from him and used it for the down payment on his own turbine.

After he bought the turbine, Jensen solicited investors, many of whom came from his extended family. As part of the sales pitch, he took a busload of potential investors to the Micon manufacturing facility. Interest in the cooperative was so high that Jensen could have had enough investors for two turbines. Thirty-eight people, including Mrs. Jensen, joined the cooperative. Each member bought 30 shares of 1,000 kWh each. In addition, Jensen and another farmer acquired another 290 shares, for a total of 1,430 shares. Members paid \$523 (DKK 3,400) per share, for a total project cost of \$748,000 (MDKK4.862). Investors financed their shares by a variety of means. Some took out loans from different lenders, and others put in their own equity.

A small local bank administers project cash flow. It receives quarterly payments from the utility and makes payments to owners twice a year. Equity owners receive the payments themselves. Debt investors have their payments sent directly to the institutions where the loans reside. Once the loans are paid off, they will receive the payments themselves.

At first, Mrs. Jensen was not happy about seeing so many large wind turbines near her home, but she now finds them quite attractive. However, she likes the fact that they are not within direct view of the back window and the patio. She still says that, although a couple of turbines are acceptable, she would object to a larger wind farm.

The Jensens undertook the project to help the environment and work together with family and friends. They acknowledge that the project's favorable financial outlook was crucial. Jensen reports no problems with acceptance from any of the neighbors since they are all shareholders. The closest neighbor is 800 meters (880 yards) from the turbines so noise is not an issue.



Figure 2.2 Three turbine cluster on Jensen Farm. Danish turbine owner Arne Jensen founded a cooperative that owns one of a cluster of three turbines (seen from the Jensen's home). Mrs. Jensen, a cooperative member, says she finds the turbines quite attractive. Photo courtesy of Thomas A. Wind.

Differences Between Conditions in Europe and the United States

Despite some similarities, there are also differences in the development of wind generation in the United States and Europe. U.S. federal policies have resulted primarily in the development of large wind power plants connected to the transmission system. (A few states have had very limited success in stimulating distributed development through incentives.) Large institutional investors finance these plants, which are owned and operated by corporations. Revenues (except for land payments) typically flow to investors outside the local area, although land owners do receive royalties or other forms of payment for the use of their land. As discussed above, Danish and German policies toward wind power encouraged or required private, local ownership by individuals (or groups of individuals), which, in conjunction with other incentives and policies, had the impact of encouraging distributed projects. What are commonly thought of as potential benefits of distributed wind generation in this country are not part of the valuation of projects in Denmark or Germany. More importantly, their policy approaches have addressed the additional costs of interconnection and grid reinforcement.

Both Denmark and Germany have relatively small land areas and high population densities whereas the United States is land-rich with comparatively few people. In Europe, developing distributed wind projects has been the preferred approach partly because land use issues limits the siting of large projects. Resource assessment, standardized siting and service, and installation were all aided by the fact that all distances are relatively short. Because populations are smaller, especially in Denmark, political influence and relationships among market, political, and government players were easier to create and nurture.

Denmark and Germany have a tradition of more government influence (to different degrees in each country) on industry and regional/local government. For instance, permitting in both countries is fairly uniform due to more federal influence. U.S. business and political traditions place more emphasis on free markets, local permitting, lower taxation, and less government involvement in the market. Because Danish and German populations are more homogeneous than in the United States, public consensus was able to effect dramatic

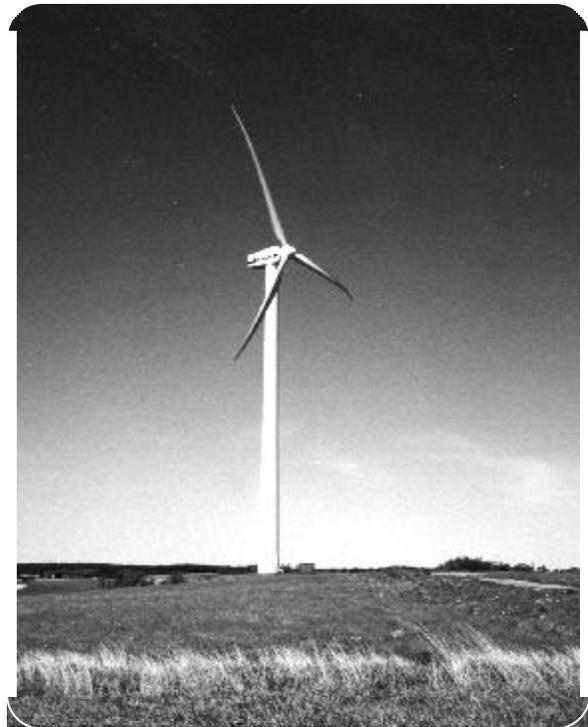


Figure: 2.3 Kægaard turbine in three turbine cluster. Wind farming is a good investment for Danish farmers like Gravers Kægaard, whose 660-kW Vestas turbine is shown here. Similar investments are not economically attractive for most U.S. farmers at present, so each project's costs and technical requirements will have to be carefully evaluated. Photo courtesy of Thomas A. Wind.

national policies supporting wind energy in those countries, especially the feed-in tariffs. With a more heterogeneous population and many competing interest groups, it traditionally has been difficult to achieve such strong policy response in the United States based on public majority opinion.

Beginning in the late 1970s, Denmark's government pressured utilities using the threat of legislation to allow access for wind projects, negotiate economically attractive (to turbine owners) prices with turbine owners for wind power, and pay for some of the interconnection costs. By the mid-1980s, when there was often enough distributed wind generation to require reinforcements to the distribution grid for new wind projects, the Danish government began providing funds to strengthen the distribution system. A national feed-in tariff was then established to formalize previously "voluntary" above-market feed-in tariffs. When Germany began adding substantial amounts of wind generation, it had its feed-law in place, as well as requirements for utility interconnection. Germany also required (and

continues to require) turbine owners to pay for the majority of grid reinforcement costs, in addition to interconnection costs. However, the mandated feed-in tariff (described below) is high enough that projects remain financially attractive even after allowing for reinforcement costs. In contrast, the United States requires that utilities allow interconnection of wind turbines under the Public Utilities Regulatory Policies Act (PURPA), but only requires utilities to pay for energy at avoided cost. Further, there is no U.S. policy covering payment of grid reinforcement.

Other differences between the United States and Europe must be taken into account in analyzing the prospects for distributed wind generation in the United States. For example, differences in utility market structures may limit the applicability of European experience to the United States. Finally, utility distribution systems in Denmark and Germany differ in important ways from those in the United States. The European systems are characterized by shorter lines, more robust design margins, and the predominance of three phase lines. A relatively weaker U.S. distribution system will restrict opportunities for integrating distributed wind domestically, as will be discussed in Chapter 3.

Policies and Incentives

In addition to mandated premium prices (“feed-in tariffs”) for wind-generated electricity, a variety of other policy and marketing incentives, together with support for research and development, are responsible for distributed wind generation’s rapid inroads into Denmark and Germany’s power markets during the 1990s. These include national targets for wind capacity (in Denmark), general public funding of national research and development programs, direct investment subsidies for turbine installations, and the development of standard market procedures such as loan application/approval processes and resource assessment approaches. Some national policies also required or provided incentives for private turbine ownership and restricted share sizes for cooperative projects to ensure widespread ownership. These latter policies foster public acceptance and impede large developer-owned projects—two key components of the European distributed wind market success.

Feed-in Tariffs

Although early wind development depended on various policies and wind industry infrastructure

developments, feed-in tariffs have been the major driver of new wind energy projects in Denmark and Germany. A feed-in tariff is the rate paid to wind turbine owners for electricity fed into the grid. The large tariffs create acceptable financial returns and risk levels for wind generation. Germany launched its feed-in tariff in 1991 with the *Electricity Feed Law (Stromeinspeisungsgesetz)*. Denmark established its most recent tariff in 1992 as part of its *Law for Wind Turbines, or Vindmølleloven*. Since then, there have been indications that suggest the feed-in rate might be on the order of 10% higher than project owners’ economic threshold in Denmark.

In 1998, wind generators in Denmark received a feed-in tariff of approximately \$0.09/kWh. Residential customers paid a retail rate of about \$0.17/kWh to purchase electricity, of which about \$0.11/kWh was for energy, environmental, and value-added taxes. The feed-in tariff was comprised of a payment equal to 85% of the small consumer pre-tax retail rate, plus an additional subsidy, plus an amount equal to the carbon dioxide tax levied on other sources of generation. An energy tax assessed on all electricity customers helped fund the feed-in tariff and pay for interconnection expenses incurred by utilities.

The German feed-in tariff was about \$0.105/kWh in 1998, down from a high of about \$0.19/kWh in 1991–1992. The structure of the German tariff is simpler than the Danish one. It requires local utilities to purchase electricity from wind at 90% of the average pre-tax electricity tariffs for all customers in the country. The size of the feed-in tariff was not based on rigorous analysis of the economics of wind projects. Rather, it was a negotiated number, influenced by the externality valuation work conducted in Germany during the late 1980s and early 1990s [Rehfeldt 1998].

Feed-in tariffs offer several advantages as a policy tool. First, they can be used equally by all project owners, regardless of tax liability or income level. Secondly, they are easy to administer and exact minimal transaction costs. The feed-in tariff level required to make projects financially viable is highly dependent on the wind resource. Thus, large tariff subsidies are not a universal requirement for providing incentives for distributed wind power in locations with better wind resources. Effective subsidies depend on the wind resource, the project’s financial parameters and costs, and

the financial thresholds required by project owners. Still, using feed-in tariffs as a subsidy results in electricity consumers paying more for wind generated energy than they might under some free market alternatives.

Germany and Denmark have less favorable wind resources than many sites in the Midwest and other regions of the United States. For instance, inland German sites typically have annual average annual wind speeds between 4.2 meters per second (m/s) (9.4 miles per hour (mph)) and 5.5 m/s (12.3 mph), measured at a height of 10 meters. Coastal sites typically have between 5.5 m/s (12.3 mph) and 6.0 m/s (13.4 mph), while wind speeds in Denmark generally vary between 5.0 m/s (11.2 mph) and 6.0 m/s (13.4 mph) inland and average about 6.0 m/s (13.4 mph) on the coast. By contrast, large areas of the United States, especially in the Midwest and Great Plains, have winds between 5.6 m/s (12.5 mph) and 7.0 m/s (15.7 mph).

Policies in Denmark

Both policy and market infrastructure developments in Denmark have been part of a constantly evolving framework since 1978, as shown in Figures 2.4 and 2.5. In the mid-1970s, private individuals initiated limited, but significant, market activity. Government subsidies began in 1979 in the form of capital grants to turbine owners. Since 1979, the government has created various capital and energy production-based subsidies. In addition to the capital grants, the period from 1979 to 1984 was characterized by voluntary utility cooperation encouraged by government leverage and persuasion. A key point is that the dynamics of obtaining such utility “voluntary cooperation” occurred in the context of a much different relationship between Danish government and industry than is typical in the United States; the Danes have a tradition of a much larger government influence in the private sector. The first private wind turbine cooperative formed in 1980. The only limitation to cooperative turbine ownership at that time was a residence criterion – members had to live within the same municipal area and no more than 3 kilometers from the turbine [Tranæs 1998]. This rule was

- Guidelines minimize permitting and zoning barriers
- Standard market processes reduce barriers and cost
- Capacity goals create market confidence
- Experienced personnel available for installation, O&M
- Owners organization provides advocacy, information, technical assistance, and political leverage
- Manufacturers organization provides political leverage, influence on technology development, and development of standardized information for market participants
- Cooperation between owners, manufacturers, and government improves policy and technology development

Figure 2.4 Elements of Danish wind market infrastructure development.

created to ensure public acceptance by making sure that those who had to bear the costs associated with the turbines, e.g., visual and noise, were the ones who would benefit financially.

Beginning in 1979, the government required utilities to share the cost of interconnection and grid reinforcement (effectively making this cost a subsidy from other customers). Costs for the latter were relatively low until the mid-to-late 1980s since the distribution grid was robust enough to handle smaller turbines with minimal or no reinforcements. Organizations of Danish manufacturers and individual turbine owners initiated important information-sharing activities well before a voluntary 1984 agreement created the first standard nationwide electricity purchase price. These organizations not only provided owners and manufacturers with the political clout to achieve such an agreement, they established infrastructure that assisted the market to move forward quickly once the purchase agreement was in place. For instance, the Wind Turbine Owners Association has provided its members with technical assistance, bargaining leverage with manufacturers, and information on turbine performance and reliability. Manufacturer and owner organizations continue to play key roles in the Danish market.

When developers began to initiate larger wind farms in 1985, the Danish government limited the

size of cooperative investment shares to encourage distributed development and make it impossible for developers to get a foothold in the market using a centralized development approach. Ownership shares were based on each owner's consumption, with one share allotted per-kWh, and a cap of 6,000 kWh per owner. In the late 1980s, a series of adjustments to subsidies occurred. Capital grants were phased out and production-based subsidies increased incrementally. In 1992, the Law for Wind Turbines relaxed restrictions on cooperative ownership share size and criteria for qualifying as "local" ownership participation. Private owners also received tax advantages including reduced rates on project revenues, deduction of expenses and interest, and accelerated depreciation.

Policies in Germany

Germany did not go through as many iterations of its national wind policy as Denmark to achieve a high level of installed wind power capacity. One reason is that wind technology had already been proven in other countries by the time German market incentives were put into place. Costs were better known and effective incentives were easy to identify. Despite the availability of Danish technology, it took Germany time to build its own manufacturing and service infrastructure and develop

processes for information dissemination and financing. These tasks were made easier by the robust German industrial and service sectors and by capitalizing on lessons learned in Denmark.

The German government relied on legislation and subsidy programs to encourage wind power markets. As shown in Figure 2.6, German government assistance included: the Electricity Feed Law; a 250-MW Wind Program, which provided capital subsidies and production-based incentives; subsidy and loan programs; and assistance from state governments. Subsidies included accelerated depreciation and subsidized loans available through the Deutsche Ausgleichsbank (DtA) at average rates of 1 to 2 points lower than market. DtA financed about 75% of all projects installed between 1990 and 1996, investing a total of about 2.5 billion Deutsche Marks (1.23 billion dollars).

Like their Danish counterparts, German land owners installed limited numbers of smaller turbines before government incentives came into play. From the beginning, an exemption in the German land-use law aided local financial participation. Restrictions in the law essentially allowed only farm-related buildings or electricity generation projects to be built on farming land. In 1986, the German govern-

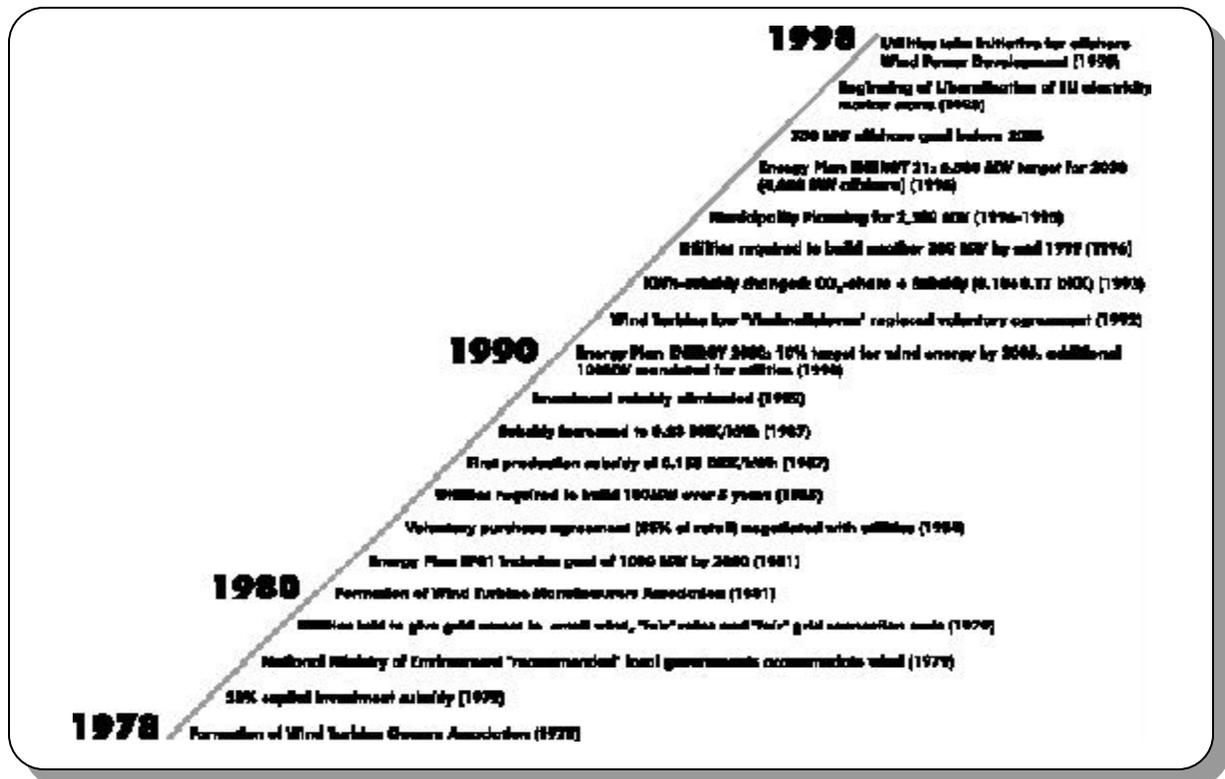


Figure 2.5 Key Danish policy developments.

ment began encouraging private turbine ownership with capital subsidies and production incentives for on-site use of power. Utilities have owned wind projects since the beginning of government subsidies, but they continue to have the smallest market share.

There is little land available for wind projects in Germany other than farm land. So many wind projects were built on farm land that eventually turbines began to be perceived by the public as aesthetically intrusive. In 1997, the Building Construction Law restricted new wind projects to areas approved by local land planning processes. This change has had the effect of shifting wind development to larger, developer-led projects. Most localities have now completed new planning designations, thereby removing uncertainty and siting barriers. As a result, the market is at an all-time high and is being allowed to adapt to changing needs, thereby maintaining public acceptance of wind energy development.

Trends in Danish and German Wind Development

Although the successful deployment of wind energy in Germany and Denmark is often referred to as a single European model of development, several characteristics distinguish their markets from each other. Although most of the new capacity in Germany continued to be connected to the distribution system as of 1998, the market has evolved rather quickly from single turbines and small clusters to larger clusters and wind farms. German wind farms, which are larger than 5 MW, exceed the size of anticipated distributed wind installations in the United States. The Danish market has also evolved from single turbines to clusters because of public criticism of uncontrolled small project development. Denmark is running out of land for additional capacity faster than Germany, and the majority of future new capacity will likely come from large, off-shore wind projects. Both countries are moving toward larger installations because of land use issues, which, in effect, allows the market to adapt to changing public sentiments.

As it has evolved, Danish and German wind development has begun to more closely resemble development in the United States. For example, German projects are increasingly owned by

- Chernobyl becomes a public policy catalyst (1986)
- Green Party emerges as a national voice for progressive policy (mid-to-late 1980s)
- 250-kW Prototype Program provides investment subsidies for first five commercial units (1986)
- 100-MW Wind Program provides investment or production subsidies (1989)
- State investment and loan subsidies encourage local wind projects (late 1980s-early 1990s)
- National subsidized loan program created through national Deutsche Ausgleichsbank
- 250-MW Wind Program creates investment or production subsidies (1990)
- Electricity Feed Law guarantees access to grid and fixes tariff (1991)
- Building Construction Law removes siting barriers but eliminates most new single turbine projects (1996)

Figure 2.6 The evolution of German wind energy policy.

developers and investors not living or working near the wind installations. It remains to be seen how this change will affect public acceptance as market penetration increases. In addition, other, larger changes are underway in Denmark and are on the horizon in Germany. In 1999, European utility market restructuring, known as "liberalization" caused Denmark to begin a phase-out of its feed-in tariff, and the market is shifting to a credit system for wind power and other green alternatives. It is too soon to know what the ramifications of this development will be. Germany's feed-law seems safe at present, but it is unclear how long it will remain in place. It will be instructional to watch the effect on wind energy markets in both countries as they become more similar to the U.S. market.

ECONOMIC PROSPECTS FOR DISTRIBUTED WIND GENERATION IN THE UNITED STATES

The widespread deployment of financially attractive distributed wind power projects in the United States faces a complex set of market and institutional issues, technical challenges, and regulatory and policy needs. Further uncertainties about the

prospects for distributed wind generation are introduced by utility restructuring. There appears to be no simple answer to the question: What role can distributed wind generation play in future utility markets? The remainder of this document will attempt to provide the reader with information to form conclusions regarding the viability of distributed wind generation.

The United States has only limited experience with distributed wind generation. From the late 1920s through the early 1950s, thousands of small windmills and turbines were installed on farms all across the country to pump water and generate electricity. However, the Rural Electrification Administration (formed in 1936) helped create a centralized electricity grid, encouraging farmers to disconnect their turbines and join the system. This ultimately led to the demise of the U.S. wind turbine industry, as the main manufacturers went out of business in 1956 [Richter 1995].

There are approximately 1,600 small turbines, 10 kW or less in size, connected to the grid, but there is little documented experience with them [Bergey 1998]. The base of experience and knowledge from which to evaluate distributed wind generation is very limited in the United States. Only a few recent installations of utility-scale wind turbines are undergoing monitoring and assessment. As of 1998, individuals, schools, businesses, and utilities had installed turbines in at least 20 distributed wind projects. Most of these projects are in the upper Midwest, where a large wind resource coexists with ample privately owned rural land. Most of the projects were installed for reasons other than pure economics. Some have used refurbished wind turbines or taken advantage of special grants or incentives for first-time projects. The state incentives in Minnesota and Iowa have especially played an important role in these early projects. Municipal utilities and rural electric cooperatives have participated using green power programs. Largely as a result of the legislation stemming from the Prairie Island settlement, which required a certain amount of renewables to be installed in the state, in 1999, a developer began plans to install 17 distributed wind projects totaling about 30 MW in Minnesota. As part of the budding interest in distributed wind generation, wind energy advocates are investigating impediments and opportunities for this power source and developing information and assistance for landowners.

Project Ownership

The market could easily support various types of ownership of distributed wind projects. However, many of the institutional and market-related challenges, requirements, and opportunities for distributed wind power depend on the specific project ownership structure. Regardless of the type of ownership, a majority of distributed wind projects will be located on privately owned land due to the location of distribution lines. Different ownership structures offer different levels of risk and financial return to landowners. They also vary in the amount of participation required from the landowner. It is important to understand how returns are allocated to local and non-local entities under different project ownership structures because this has implications concerning the size of local economic impacts, and in some cases, public acceptance. The degree to which distributed wind power projects are integrated into the local economy may be key to public acceptance and the long-term viability of distributed wind generation in the United States. This section also describes some of the unique challenges and opportunities for distributed wind power faced by various types of potential owners.

Different project/ownership structures that provide varying degrees of local financial participation are:

- utility (including public, private, vertically integrated, generation companies, or distribution companies), developer, or energy service company ownership;
- rural electric cooperative aggregation of output from individually owned turbines;
- regional wind energy cooperative;
- private cooperative; and
- individual landowner.

None of the above ownership structures is mutually exclusive. It is quite likely that several would be present in a vibrant market. The two primary ownership structures for the few existing U.S. distributed wind projects are individual ownership with financing from private capital, grants, or subsidized loans, and utility-owned green power projects.

Utility, Developer, or Energy Service Company Ownership

As a project owner, utilities could use distributed wind generation for green power programs. There are four reasons that distributed wind might be preferable to utilities, as compared to bulk wind generation: cost, customer preference for a local energy resource, control of the project, and local access for O&M. Connecting wind power to the distribution system can be less expensive than connecting it at the transmission level, if few or no system reinforcements are necessary. While not based on survey or other research, some observers see growing evidence from projects such as those in Colorado, Wisconsin and Nebraska, that some people prefer the source of their green power to be close to where they live. For many people, this means that green power generation would have to be smaller and connected to the distribution system. Utilities, especially small public ones, might also be interested in managing and monitoring a project using new technology. For this reason, they might prefer to have the project nearby, which also helps keep O&M costs down.

Some municipal utilities have long-term contracts to purchase generation exclusively from certain suppliers. However, even if they do not have such contracts, they often rely on other utilities to supply generation. Even if they do build their own generation facilities, they may have to purchase transmission access from other utilities if their resources lie outside of their municipal border. An alternative strategy would be to install wind power on a distribution system. Participating in joint projects with other municipal utilities is a way to reduce project risk, lower costs, build larger projects, and find markets for wind power. A good example of joint ownership is the 2.25-MW Iowa Distributed Wind Generation Project at Algona, Iowa. The project, which came on line in October 1998, is jointly owned by seven municipal utilities.

Cooperative Power (a generation and transmission cooperative) and Dakota Electric Association (a distribution cooperative) collaborated on a distributed wind generation project in Minnesota in 1998. Their experience provides important lessons for future projects, according to a recent report [Tennis et al. 1998]. Advocacy and public outreach were critical activities. Members championed the project with their boards. Outside advocates provided technical assistance, public outreach, and marketing credibility. The advocates also served as

liaisons between the boards of Cooperative Power and Dakota Electric and the wind energy community. Everyone involved in the project agreed that sharing information and experience from other projects was extremely helpful and that compromise was essential. To keep project costs (and green power prices) as low as possible, the utilities and the wind developer negotiated a 15-year power purchase agreement.

Issues affected by land ownership, i.e., local economic return, landowner and community acceptance, are similar for utilities, wind project developers, and energy service companies. Any of these entities could choose to buy land for a distributed wind project if it is available. However, a more likely alternative would be to lease the land and offer the landowner either a one-time payment, a fixed periodic payment, or an annual production-based payment for the use of the land. A one-time payment is most common in Denmark. All three approaches have been used for land leases in Minnesota, and, theoretically, all three can provide equivalent returns, on a net present value basis, to landowners.

Corporate entities such as energy service companies could aggregate projects to increase economies of scale in the purchase, installation, and operation and maintenance of distributed installations. Further, project aggregation could reduce transaction costs and increase market leverage in areas like project financing and establishment of power purchase contracts.

Rural Electric Cooperative Aggregation of Output from Individually Owned Turbines

A rural electric distribution cooperative could aggregate electricity from turbines owned by individuals or private cooperatives. The distribution cooperative would collect and market the electricity. It could also be responsible for securing loans or selling bonds to provide capital for projects. In other words, the cooperative would facilitate landowner access to debt capital. Such an arrangement may be more feasible for electricity cooperatives than for other utilities because of their (cooperatives) unique relationship to landowners. This ownership structure allows greater financial participation by local landowners. Possible benefits for the rural electric cooperatives might include:

- offering new service to members, which could build customer support and loyalty;

- strengthening the distribution system or providing other distribution system benefits;¹
- providing diversity and flexibility in a deregulated and more competitive market; and
- proactively managing uncertainty with respect to possible environmentally driven mandates.

Regional Wind Energy Cooperative Ownership

A regional wind energy cooperative could aggregate and market wind power from hundreds or thousands of small, dispersed independent producers [Brakken 1995]. The Rural Energy Producers Electric Power Cooperative (REPCO) advocates this model, which was developed for the Great Plains. The regional cooperative utility would give small producers technical and negotiating support as well as a way to market power to wholesalers on the open market. Power producers would benefit from being able to value the portion of their generation used on-site at retail rates, a strategy that might not be possible under a private cooperative ownership scenario. The margin between the cooperative's purchases of excess power and its sales to wholesalers would cover its operating costs. Many technical member services would be similar to those of the Danish Wind Turbine Owner's Association, which played a key role at the beginning of Denmark's wind market development. The major difference is that the U.S. regional cooperative utility would also aggregate and market power. These functions would allow the utility to operate from market-based revenues instead of member dues, as is the case in Denmark.

Private Cooperative Ownership

Private cooperatives could be structured like agricultural cooperatives. In some areas, they might work in partnership with a local rural electric cooperative. This ownership structure would be similar to Danish cooperatives, in which landowners combine their financial resources to purchase one or more turbines to provide a source of revenue from the sale of electricity. The wind turbines are installed on one or more shareholders' land, but all the investors share in the revenue generated. This ownership structure provides significant financial return for the landowner, but also creates more risk and involvement. It has the advantage of sharing project risks, however, because each member reduces his or her personal

risk of financial loss to levels below those from an individually owned project. A landowner could participate in a private cooperative but could also simply lease his or her land to it. Because cooperative projects can maximize local economic benefits while keeping risks to individuals low, they make an attractive structure for governments interested in promoting economic development and diversification of the economy. There are a number of reasons cooperative ownership has not been used in this country thus far:

- Small projects cannot compete against large wind farms because they are more expensive.
- Utility avoided costs are too low to provide adequate returns at current wind project prices.
- There is a lack of understanding of wind energy economics and how to establish and operate a wind project.
- First projects often entail significantly more time, cost, and risk than subsequent efforts.
- Existing power cooperatives may resent private cooperatives and compete with them.
- Sales of easements to developers or utilities can preclude future cooperative ownership.
- Establishing power-purchase agreements with utilities and meeting technical and cost requirements for interconnection must be accomplished on a project-by-project basis and may require professional assistance.

Encouraging cooperative projects will require establishing a workable U.S. model. This process would be facilitated by the development of pilot projects.

Individual Ownership

Individuals wishing to own large wind turbines face many of the same challenges as prospective cooperative owners. However, the challenges to owning such turbines are greater for individuals because they usually have smaller financial resources. In addition, they have no one to share the burden of navigating through the maze of development issues. Recent experience in Minnesota is that many

¹Wind will provide significant distributed benefits only in very specific, limited situations. It will more often provide modest system benefits, such as a reduction in area transmission losses.

landowners have preferred to sacrifice the larger potential returns from owning their own turbines by leasing their land to developers or utilities. Leasing reduces the risk from project failure and the hassles and responsibilities of project development and operation. Since there is no long-term experience with wind projects, these risks and responsibilities are not well understood among the land owner community. Some landowners have expressed a lack of confidence and understanding about how to select payment types and negotiate terms. They are uncertain about how (or if) turbine projects or various payment contracts might affect the value of future property transactions and how such effects would be handled. Such uncertainties stemming from lack of information present challenges in many early markets.

In addition to many of the same difficulties faced by individuals wishing to own large wind turbines, those wanting to own small wind turbines face additional challenges. Smaller turbines are more expensive, per unit of rated capacity and energy produced, than their larger counterparts. Other serious challenges include costly requirements for interconnection or liability insurance and outdated covenants or zoning requirements based on other technologies or building structures. Possible approaches to reducing these challenges include developing consistent interconnection requirements across the United States and a national code on tower height restrictions. Documenting and disseminating the operational, safety, and performance experience from grid-connected small wind generators to demonstrate their successful track record may also be helpful in reducing liability insurance requirements and meeting utility concerns about safety and performance issues.

Grid-connected small turbines that produce power significantly in excess of the owner's load will usually require net metering to be financially attractive. Under net metering, the meter is allowed to run forward when electricity is supplied from the grid to the customer, and backward when the customer produces excess electricity. This allows the customer to pay only for the electricity he or she uses from the grid, net of the total wind turbine production. Therefore, the amount paid for the wind-generated electricity under this arrangement is the retail rate of electricity. (Net metering is discussed in more detail in the policy section later in this chapter). If all wind-generated electricity can be used instantaneously on site (i.e., it does

not have to be fed back to the grid), net metering does not increase its value.

There are over 180,000 off-grid homes powered by small-scale renewable energy [Perez 2000]. Customers appear to be motivated primarily by a desire for independence from the utility grid, increased power quality, and concern for the environment. Since approximately 24% of the U.S. population live in rural areas, where there is a predominance of single phase lines, small wind turbines could easily accommodate many of those applications.

Project Financing

U.S. lenders have the ability to finance distributed wind projects if they choose to do so. However, a loan for a wind project is not like a mortgage or car loan. It is based on the size of the project's projected revenue stream and the likelihood the project will be successful. Many potential lenders find it difficult to evaluate these factors because there are few distributed wind projects in this country. Data from them are not widely available and may not be generally applicable. Because there is a lack of familiarity with the technology, lenders are concerned about achieving a steady cashflow. The perceived risk results in unwillingness to lend or in higher interest rates. If financing is secured, transaction costs are proportionately higher.

There is little experience financing privately owned turbines for distributed applications in the United States. For this reason, the authors did not investigate project financing in detail for this report. However, there are reports that even commercial developers find it more difficult to obtain financing for a smaller project than for a large wind farm. One reason is that institutional lenders are typically attracted to larger deals. The relatively small amount of money required to develop a distributed wind project may not be of interest to them.

A few individuals have obtained loans from banks for turbines rated between 10 kW and 100 kW, but little is known about such transactions. They have occurred between farmers and local banks, where officials were acquainted with the farmer, the turbine manufacturer, or both. Many of the 17 newer distributed wind projects in Iowa took advantage of refurbished turbines, gifts, grants, cash, or special low-interest loan programs that have limited funding caps. A few utility projects in Iowa and other states used financial support from

the Turbine Verification Program sponsored by the Electric Power Research Institute and the U.S. Department of Energy.

Project financing depends on the ownership structure of a specific distributed wind project. Historically, investor-owned utilities have had the ability to spread investment costs across their entire rate base, which resulted in lower cost of capital for projects with higher risk profiles. Under newer utility structures, where generation assets and functions are divested from transmission and distribution, generation utilities may be able to use balance-sheet, or corporate finance, where debt and equity investors hold claim to a diversified pool of corporate assets. For this reason, their rates can still be lower than those for projects developed by independent power producers, where the debt and equity investment is secured by only the one project. Since private owners must borrow funds at consumer rates, their financing costs would be the highest. Municipal utility financing is currently the least expensive way to finance a new wind project because public utilities can use tax-free debt. However, this type of financing may not be a long-term option, depending on the outcome of restructuring legislation.

Local Economic Benefits

The installation of wind turbines can stimulate economic development in the local community. Impacts could be negative if the wind power displaces a local resource, significantly increases the price of electricity, and/or relies entirely on imported technology and labor. As shown in Figure 2.7 the economic advantages of distributed wind generation include such direct benefits as job creation, tax revenues, and fees for service. Wind projects also create jobs in support service industries, increase local economic activity, and help diversify local economies. Quantifying these benefits proved to be a major challenge, however, because the sixteen studies reviewed for this document used inconsistent methodologies, definitions of terms, and interpretation of basic economic sectoral data. Taken together, however, the studies suggested a number of important points to consider in evaluating the local economic benefits of distributed wind generation.

Manufacturing Sector Employment

The economic benefit from manufacturing jobs is one of the reasons for strong political support for wind power development in Denmark, where the entire country is small enough to be considered the

local economy. In 1999, the Danish Manufacturers Association estimated there were 13,800 jobs in the turbine and component manufacturing industries [Danish, 2000]. The capacity of turbines manufactured that year was 2,241 MW, or about 6 jobs per megawatt of turbine capacity. A recent study of potential benefits from wind power in Wisconsin [Clemmer 1994] showed that the largest economic benefits come from local manufacturing and construction of wind turbines, whether the turbines are used for large windfarms or distributed projects (this finding assumes such activity is conducted with local labor and resources). Specifically, local jobs and earnings were shown to be larger than for similar expenditures on existing utility service. Further, while states or regions may be interested in wind power manufacturing for its economic benefits, most local economies in the United States will not experience similar benefits because they are unlikely to have turbine or component manufacturing plants in their jurisdiction.

Construction Jobs

The issue of market size and maturity comes into play when considering the benefits from construction jobs. These benefits are significant but short-lived—unless a steady stream of projects continues to come on-line. A recent study of a regional area in Minnesota, sponsored by the Southwest (Minnesota) Regional Development Commission (located in Slayton, Minnesota) found that installation labor costs for 100 MW of wind capacity using 600-kW turbines were nearly identical regardless of whether the turbines were erected at a single location or at many dispersed locations [DanMar 1996]. The study showed slightly less than one job per megawatt installed. A Danish study estimated three construction jobs per megawatt from data on actual expenditures for wind turbine construction [BTM 1995]. However, depending on where the construction labor pool comes from, a significant portion of wages paid may leak out of the local economy, providing no local benefit.

On-going Jobs in Operations and Maintenance

Permanent jobs in operation and maintenance amount to about 0.1 to 0.5 persons per-MW of installed capacity, according to wind industry experts in Denmark, Germany, and the United States. The lower figure may be more representative of large wind farms at a single location, while the higher figure would apply to clusters of turbines sharing a staff. With sufficient development density, the figures could conceivably converge.

Additional Tax Revenues

The local property tax base will be increased when wind turbines are built. Depending on the local tax rate, and possibly on local tax treatment of wind plant property, that contribution could be significant. Smaller wind clusters could be treated in some states in a manner different from larger plants (due to exemptions from property tax for plants under a certain size) and could contribute less than large wind plants. Sales tax is another source of local or regional revenue, although it is only a one-time payment. It too may be eligible for reductions or exemptions in some states, possible for specified project size limits. For both property and sales taxes, the capital intensive nature of wind power projects puts them at a life cycle cost disadvantage compared to other sources of generation where the capital investment is lower, but ongoing fuel costs are much higher. Income tax is the final type of potential local or state tax revenue. It is important to recognize that tax benefits and tax incentives negate each other.

Local Ownership as an Economic Stimulus

The ongoing operation of the wind project will generate revenue for the local community. The impacts on the local economy depend on who owns the wind plant. If the wind plant is owned locally, the owner(s) have a revenue stream from the production of electricity. The electricity may either be used on-site to displace purchased electricity, or may be sold in the wholesale market. The magnitude of the local economic activity generated by this revenue stream depends on the size and financial attractiveness of the project. The Southwest Regional Development Commission study suggested that local ownership of 100 MW of wind clusters would create 25 to 150 more jobs and \$700,000 to \$4.3 million more value added to the local economy over the project life than a wind farm owned by distant investors [DanMar 1996].

Induced Effects on the Local Community

Economic activity generated by manufacturing, construction, and maintenance ripples through a local economy. The effect on the local economy is multiplied as dollars circulate. Drawing from numerous studies of similar economic activities, it can be estimated with a high degree of confidence that for every million dollars spent in a local economy on wind-related activities, the economy should see 1.5 to 2.5 million dollars in total economic activity. The extent of indirect benefits on a local economy depends on many

Direct Benefits

Employment impacts associated with wind plants can be characterized in three groups:

- Jobs associated with wind turbine manufacture
- Jobs associated with wind plant construction
- Jobs due to wind plant operation and maintenance

Additional tax revenues may be generated from sales, income and property taxes. The relative size of each will depend on the local tax rate and possibly on local tax treatment of wind plant property.

Landowner revenues from the project can come from either leasing the property or from the sale of electricity to the local grid.

Indirect Benefits

Employment in the sectors that support and supply the primary industries associated with manufacture, construction, and maintenance.

Induced Benefits

Jobs induced in the community due to increased economic activity or due to higher incomes of turbine owners.

Other Benefits

Economic diversification is an additional benefit to the local economy.

Figure 2.7 Potential local economic benefits of distributed wind generation.

factors. For example, the indirect benefits of installation labor provided by non-local crews would be very short lived.

Economic Diversity

One benefit of privately owned distributed power is the diversification and expansion of the income base in agricultural and rural areas. This diversification creates more stability in the local economy. In Europe, the increased stability of local farm economies has generated political support for wind generation at all levels of government.

In formulating the above insights, the Southwest Regional Development Commission study was the most valuable U.S. study [DanMar 1996]. The study was based on engineering cost estimates for wind turbine installations, used an appropriate methodology for modeling regional economic activity, and analyzed both wind farm and cluster development models. The study did not take into account the negative impacts of displacing conventional power generation or of paying slightly higher electricity prices for wind, which diverts consumer spending away from other activities. Another study [Clemmer 1994] did account for those negative impacts and looked at the relative economic impacts of developing small turbines (10 kW) and larger wind farms (10 MW). The Danish Wind Turbine Manufacturers' annual

survey provided useful data on direct and indirect employment in the Danish wind industry [Danish 1998]. The BTM analysis of Danish Wind Turbine Manufacturers' data provided excellent insights into manufacturing sector data [BTM 1995]. The Bureau of Economic Analysis (BEA) report was also consulted extensively [BEA 1992].

INFRASTRUCTURE ISSUES FOR DISTRIBUTED WIND IN THE UNITED STATES

The development of a U.S. market for distributed wind generation will require additions and enhancements to an infrastructure that currently serves a wind industry based on large wind plants. Although large wind power plants and smaller distributed installations both rely on wind turbines, the dispersed nature of the latter has different implications for resource assessment, siting and permitting, financing needs, power purchase contracts and interconnection standards, U.S. manufacturing and service industries, and information dissemination to actual and prospective owners and the financial community. Experience in Europe has shown that it is useful to begin activities to build infrastructure in many of these areas prior to significant market activity. However, development of infrastructure for O&M, resource assessment, manufacturing, and financing will depend to a varying extent on market volume and activity.

Resource Assessment

The basic approaches to wind data collection are the same for distributed projects and wind farms. However, resource assessment costs for distributed generation are likely to be higher on a per-MW basis in the United States. Improved public access to wind resource assessment information, tools, and data sets could help reduce costs somewhat for smaller projects. However, there are limits to how much costs can be curtailed if U.S. wind resource assessments continue to rely heavily on field measurements. A number of states, for instance, Iowa, Minnesota, Nebraska, and Wisconsin have collected wind monitoring data and currently make it publicly available from state energy offices or other agencies.

The less expensive computer wind flow models used in Europe for wind resource assessment are generally not a viable alternative in the United



Figure 2.8 Spirit Lake 250-kW turbine. Spirit Lake (Iowa) Elementary School has already earned enough money from operating its 250-kW Wind World turbine to finance a new computer lab. The development of an infrastructure to support resource assessment, manufacturing, financing, and operations and maintenance will encourage the deployment of other projects like this one. Photo courtesy of American Wind Energy Association.

States. Virtually all wind characterization in Denmark occurs via the PC-based Wind Atlas Analysis and Application Program (WASP), which was developed and is supported by the Risø National Laboratory. WASP can create regional wind patterns and calculate local wind conditions. Its prediction error is $\pm 10\%$ in the gentle terrain typical of Denmark but is significantly less effective for defining site-specific wind conditions in the United States. The latter's size and variable topography present modeling challenges that lead to greater wind prediction uncertainty. The coarser network of U.S. meteorological stations forces interpolation techniques to be applied at greater distances from known data sources. Furthermore, energy prices and sales margins are much lower in the United States. Hence, the tolerance for wind speed uncertainty is also much lower.

Siting and Permitting

Siting and permitting for distributed wind turbines are far more challenging in the United States than in Denmark and Germany, which have standardized guidelines. In the United States, processes to gain government approval or garner public acceptance must be reinvented for every locality. Rules created for another set of circumstances can be misapplied to wind projects. For example, local boards, which have sole control over interconnection requirements, can derail a project by using faulty assumptions concerning safety or operational aspects of small turbines. In addition, wind projects can run into zoning problems due to setback requirements (for safety) or visual and noise impacts. Existing codes restricting tower heights for other structures can be a barrier for siting small wind turbines. There are good references that identify siting and permitting concerns, and can guide a prospective project owner through the process [Daniels 1997; NWCC 1998].

Manufacturing and Service Industries

The United States has the industrial infrastructure to build quickly whatever manufacturing capability that distributed applications could realistically demand. Once manufacturers and maintenance organizations see potential financial return with a reasonable level of risk, there is no reason why they cannot step in to supply the market. European manufacturers have historically provided a substantial share of the U.S. wind farm market.

However, rotors and towers for turbines in the 700 kW - 1.6 MW range are too large to ship economically because they do not fit in standard crates. Domestic manufacturing of these components will be a necessity.

Distributed wind generation faces the same "chicken-and-egg" problem as other renewable energy technologies. The small number of distributed projects increases capital costs. The small number of installations also raises the cost of operations and maintenance. The most effective way to lower costs is by increasing demand for distributed wind generation. Although industry has the resources to meet increasing market demand, such demand is dependent on lowering costs through higher volume. In the meantime there are several activities that manufacturers and/or developers could undertake to encourage the development of a distributed wind market:

- working together to provide standard cost information to the public;
- working in close cooperation with landowners and other wind energy advocates to build political support for market policies;
- developing approaches, such as aggregating purchases to create discounts, to help owners obtain access to capital;
- participating in information dissemination and marketing activities;
- developing and/or demonstrating project ownership models and financing approaches;
- working with advocates, landowners, and other potential market participants to create public support for distributed wind power; and
- working toward equitable interconnection standards for distributed generation.

Information Dissemination

Most potential owners of distributed generation want complete information on evaluating, developing, installing and operating wind projects. Wind advocates have already performed substantial work in this area. Technical expertise is available from organizations such as the American Wind Energy

Association and the Utility Wind Interest Group. These organizations can also refer potential owners to individuals with relevant technical experience.

There are several excellent books and reports available to help guide landowners and utilities in exploring the feasibility of distributed wind projects [Daniels 1997; Lange and Grant 1995; Schoenrich and Nadeau 1997; Smiley and Clemmer 1998; Wind and Vanda 1998; and Wind 1996]. Other information is available from the American Wind Energy Association, the U.S. Department of Energy, the Minnesota Extension Service and Department of Agriculture, and state agencies in New York, California, and Iowa. In addition, the Renewable Energy Policy Project has several issue briefs on distributed wind generation on its website at <http://www.repp.org> [Dunlop 1996; Starrs 1996; and Suagee 1998]. Most research and information addresses ownership by farmers, other rural landowners, and public utilities. However, there are also a few investor-owned activities. The body of experience demonstrates the breadth of interest in the distributed wind market.

Local, regional, or state economic development agencies, extension services, and agricultural departments are traditional sources of information and assistance for U.S. farmers and other rural landowners. These organizations, which do not currently have expertise in wind technology, might be a logical entity to deliver such assistance, but would need technical support to set up programs for potential owners.

Distributed wind projects in the United States can be a valuable source of information, insight, and experience. They can be a source of information for project feasibility studies, policy research, and to investigate and disseminate lessons learned to market participants and regulatory and legislative audiences. For example, the Turbine Verification Program Phase III, sponsored by the Electric Power Research Institute and the U.S. Department of Energy, is demonstrating how large wind turbines perform when connected to a utility's distribution system. There are nearly two dozen projects using utility-scale turbines. There are also more than a thousand small systems connected to the grid, with millions of hours of operational experience. Because many of the small systems use older technology or received special financing such as grants for first-of-a-kind projects, their experiences may be less applicable to the new distributed wind market.

POLICY RESPONSES TO DEPLOYMENT CHALLENGES IN THE UNITED STATES

Various policies and incentives exist at the state and federal levels to encourage wind market development in general, e.g. the federal production tax credit, and some are designed to specifically encourage distributed wind, e.g. net metering for small turbines. While federal policies and incentives can be applied to distributed wind power in theory, in practice they have resulted primarily in the development of large, non-distributed projects. A few states have had limited success in promoting distributed projects with their own incentives.

The economic and financial challenges facing distributed wind power are unlikely to be resolved on a widespread level without further regulatory, legislative, or financial assistance. The challenges, which reach across different forms of project ownership, include:

High Costs. Most distributed wind projects are not economical based on a revenue stream derived solely from typical utility avoided cost or wholesale electricity rates.

Competition from Wind Farms. Falling costs from large wind farms creates competitive pressure on distributed wind generation. Utilities can meet regulatory requirements with fewer procurements of larger wind farms.

Difficulty in Raising Capital. Obtaining financing for distributed projects is reported to be more difficult than for large wind farms. Transaction costs for financing are proportionately higher.

Perceived Risks Are Higher than for Large Wind Farms. There are few real world distributed projects, and data from them are not widely available. Available data are not always generally applicable.

Lack of Familiarity with Distributed Wind Projects. Lenders are either unwilling to provide financing or require higher interest rates than for wind farms.

Disproportionate Transaction Costs. Because they are smaller than wind farms, distributed wind energy projects are disproportionately affected by the "transaction costs" of contract

negotiations, legal fees, permitting, technical assistance, liability insurance, and the effort involved in gathering necessary information.

Competition with Other, More Familiar Investment Opportunities. Small investors may be more likely to pick a familiar investment such as real estate, a new business, stocks or bonds than they are to invest in an unfamiliar new technology.

Policy Options and Financial Incentives

A broad range of policies and incentives is available to support wind energy development. Some of these are only appropriate for either state or federal implementation, while others could be (or have been) implemented by any combination of the two. Potential and historic policies and incentives are discussed below.

Policies Specific to Distributed Wind

A relatively small number of policy options have been identified in the literature solely for distributed wind power (relative to those for wind power in general). A recent NWCC report reviewed state policy options for supporting wind power projects [Rader and Wiser 1999]. The report identified the following policy options as potentially helpful for incentivising grid-connected distributed wind power in particular:

- standard power purchase contracts;
- predefined interconnection requirements; and
- net metering.

Power Purchase Contracts. The report stated that predefined power purchase contracts and interconnection requirements would simplify negotiations and reduce transaction costs for both the selling and purchasing parties of a distributed project. They would also speed the contracting process, improve prospects for project financing, and ensure that all sellers are treated equitably. The term “predefined interconnection requirements” should not imply that all distributed wind projects can or should be interconnected in a single manner. Rather, requirements should allow flexibility in meeting specific standards. An important issue in the area of predefined contracts is that various new contract approaches, which can

provide wind with alternative ways to capture value, may emerge in the new commodity-based electricity market. In such markets, long-term contracts will not necessarily be the way to maximize revenues.

Interconnections. As discussed in Chapter 3, almost every distributed project using turbines rated above 20-25 kW currently requires an evaluation of the local distribution system characteristics to determine feasibility and ensure proper interconnection. The cost of such evaluations is a large barrier to the deployment of many projects. However, if a set of standards is established for interconnection, power quality, safety, equipment design, and other criteria, then utility engineers will be able to begin developing repeatable, simplified procedures for similar distribution system conditions, using certified equipment. This does not imply that a single procedure or approach should be required. Rather engineers and utilities should be free to develop or modify procedures to meet the standard. The IEEE interconnection standard currently being proposed should help address this problem considerably. With standards, smaller projects would require little if any specialized engineering expertise. Furthermore, less engineering would also be required for the larger projects or for analyzing the combined impact of many smaller turbines on a particular distribution grid.

Net Metering. Net metering can be an important incentive for small distributed systems that are located on the customer side of the meter, although it often not enough to create an acceptable return on investment, and it does not overcome non-financial barriers. At least twenty five states had net metering provisions for wind turbines as of mid-year 2000. The allowable size cap for these ranges from 10 kW (five states) to no limit (three states). Seven states have caps of 100 kW, with the remaining states having caps between 10 and 100 kW. In net metering, a customer uses a meter that can run in both directions, depending on whether he or she is purchasing electricity or feeding it back into the grid. Therefore, net metering allows the customer to “bank” excess generation for later use. By running the meter backward whenever feeding excess generation into the grid, the customer is effectively obtaining the amount of the retail electricity tariff for the

wind-generated electricity, as long as he or she can use all of the electricity at a later time. At the end of the billing period, the customer is charged for any net energy use. Depending on the details of each net metering program, if net energy production is greater than consumption from the grid for each billing period, the customer may be paid for excess generation (typically at the utility's avoided cost), allowed to carry the amount forward to offset consumption in future periods, or required to forfeit or "grant" the excess electricity to the utility.

Net metering customers receive a subsidy from other customers in the form of free use of the electric distribution system for the electricity fed back. However, proponents of net metering note that this subsidy is negligible in cases where the customer generator size is a very small percentage of the power level of the local distribution system. Further, they note that potential size of such a subsidy can be kept to minimal levels by capping the amount of renewable generation allowed to qualify for net metering [Starrs and Wenger 1998].

Under the Public Utilities Regulatory Policies Act (PURPA) of 1978, utilities are required to purchase electricity from Qualifying Facilities (QFs), which include small power producers (SPP) such as wind generators. The Federal Energy Regulatory Commission (FERC) has ruled that utilities cannot be required to purchase power from renewable energy producers at a price in excess of the utility's avoided cost. However, many state utility commissions have taken the position that net metering falls into the area of state regulatory jurisdiction over retail practices of electric utilities, which are not preempted by FERC rulings or other federal law. A recent Iowa district court decision found that federal law does indeed preempt state rules "...requiring a utility to purchase energy from a QF at a rate in excess of the utility's avoided cost rate" [Green Power Network 2000]. The case is under appeal, and final resolution of this issue will be obtained in higher courts. Regardless of the outcome, the future of both PURPA and net metering are unclear under restructuring. Net metering is a complex issue, and will become more complex in states undergoing restructuring. As restructuring progresses, and multiple entities begin to sell power and manage the

grid instead of the single, vertically integrated utility, new net billing arrangements may have to be made to accommodate new market players, and the value to wind turbine owners of their net metered power may change in a variety of potential ways. However, it is seen as likely that SPPs will continue to be granted access to the grid under a restructured market, and that the rate which SPPs can obtain for power sold to the utility will be driven by competitive pressures [EREC 1998].

Existing State Policies. The extent to which policies and incentives have been adopted to incentivize distributed wind power at the state level varies widely. Minnesota and Iowa lead the nation. Incentives adopted in those states are shown in Figures 2.9 and 2.10 [Shoenrich and Nadeau 1997; NCSC 1998; Ahrens et al. 1996]. These two states have had only limited success in stimulating a new market and creating acceptable financial returns for certain projects. There is a range of opinion about what combination of financial and/or other types of incentives or actions may be necessary to overcome possible remaining market barriers and create a larger amount of market activity. In addition, needs for incentives and actions to support market development of large and small systems are significantly different.

Other Policies Potentially Useful to Distributed Wind Power

The following is a survey of other financial incentives that, while not exclusive to distributed wind systems, could support their development. The NWCC state policy options report reviews many of the following incentives for their ability to reduce market barriers, improve project economics, and increase market penetration of wind power in general (i.e., not specifically distributed wind power). Several states have implemented one or more of these incentives. In addition, some of these incentives are appropriate as national policy tools.

Production Tax Credit (PTC). Production tax credits or investment tax credits (ITC) may not be particularly beneficial to smaller owners of distributed plants who may not have sufficient tax liability against which to take the credits. If tax credits were designed to be refundable, i.e., not just usable to offset tax liabilities, their value to many investors would be increased.

As a way around this tax dilemma, it may be more beneficial for some land owners to take energy production-related royalty payments from a developer who can use the tax incentives [Schoenrich and Nadeau 1997]. The developer would in turn pass the tax benefits through to the landowner via the royalty payment mechanism.

Investment Tax Credit (ITC).

Existing ITCs sponsored by states are more common for small wind turbines, although states have used them to support larger systems as well. In addition, although PTCs are often viewed as more effective than ITCs because they incentivize energy production (and therefore minimize unreliable hardware), the simplicity of ITCs may make them generally more appropriate for small turbine investments. ITCs improve after-tax cash flow, but may result in reduced federal PTC payment if applied at the state level.

Sales Tax Reductions. Wind projects, whether distributed or not, whose state sales tax rates typically range between 4% and 8%, generally have high sales tax burden relative to fossil-fuel fired facilities because they are more capital intensive.

Property Tax Reductions. Property taxes vary from less than 1% to more than 10% of the assessed value. Again, the higher capital cost and lower operating cost of any type of wind plant tends to put them at a disadvantage compared to fossil-fired generation plants. Opposition to proposed property tax reductions or exemptions for wind projects can develop from local communities that do not want to lose the potential revenue, or perceive (perhaps erroneously) higher burdens on government services or infrastructure costs resulting from such projects. Maximizing local financial participation might be an effective approach to overcoming this potential problem.

- Net metering for turbines smaller than 40 kW
- Property tax exemptions for residential and commercial systems less than 2 MW, partial exemptions for systems greater than 2 MW
- Sales tax exemptions
- \$0.015/kWh production incentive grant for up to 2 MW, 10 year period, total capacity ceiling
- Low interest loan for farmers buying into a wind cooperative, 1 MW maximum project size
- Qualification for low interest agricultural improvement loans
- Requirement for standard power purchase contract for small projects
- Projects 5 MW or smaller exempted from state power plant siting process
- Wind education and outreach courses for farmers, local landowners, and others
- Accelerated corporate depreciation allowance

Figure 2.9 Incentive programs for distributed wind power in Minnesota.

- Alternate Energy Revolving Loan Program through the Iowa Energy Center, with funding provided by investor-owned utilities - 0% interest loans for up to 50% of project costs up to \$250,000 (capped by appropriation levels - \$180,000 for small wind (below 10 kW) and \$360,000 for large wind (above 10 kW) for 1997-1999.
- Property tax reduction through the Iowa Alternate Energy Production Law
- State sales tax exemption for equipment and materials used to manufacture, install, or construct wind energy systems
- Net metering
- Low-interest loans available from the Iowa Energy Bank through the Iowa Department of Natural Resources

Figure 2.10 Incentive programs for distributed wind power in Iowa.

Investment Grants. Very few states currently offer grants for distributed wind. Grants are direct cash payments, either up-front or spread out. They may be contingent upon reaching performance or design objectives.

Production Incentives. These incentives can be either a direct cash subsidy or price support payment (grant) based on electricity production.

Loan Subsidy Programs. These programs are offered by a government agency or through arrangements with private lending institutions, local authorities, or electric utilities.

Loan Guarantees. These guarantees promise loan repayment to lenders and shield creditors from project risks. Loans for some projects may require such guarantees.

Demonstration Projects. Demonstration projects help build confidence with the financial community and other potential owners. They can also help test and refine new policies as well as provide information for the commercial market.

There are few policies and incentives in place at the national level to benefit distributed wind generation, or, for that matter, wind generation in general. The federal wind energy production tax credit has clearly benefitted developers of large wind power plants and stimulated a strong U.S. market. However, it has not yet produced a significant number of distributed plants. Accelerated depreciation on turbines and equipment may also be beneficial to wind plant owners. However, the issue of tax liability again enters into determining the value of this incentive.

There are some federally sponsored loan programs that might be appropriate for distributed wind generation, if laws were changed to make wind projects eligible. Such programs are currently available through the U.S. Department of Agriculture, the U.S. Department of Health and Human Services, and the Bureau of Indian Affairs. Government agencies could help individual turbine owners aggregate several small projects to secure lower financing from transaction costs as well as reduce the risk of default. Aggregation may also enable small projects to obtain commercial loan terms. With a government agency as the aggregating agent, the owners might be able to use long-term, tax-exempt debt funds.

Congress has introduced a number of proposals that could help, to varying degrees, create a viable market for distributed wind. This includes bills that would establish net metering, standardized interconnection and safety standards, renewable portfolio standards, and public benefits funds for renewables.

PARTNERSHIPS

U.S. manufacturers, developers, owners' representatives, regulators, and utilities could work together to establish standard approaches for market processes such as power purchase contracts, information dissemination, and wind resource assessments. Standardized approaches could help reduce transaction costs. Such collaborations could also put pressure on financial and insurance companies to develop products better suited to the needs of distributed wind projects.

With encouragement, local financial institutions could develop new types of loans for farmers to be used in providing equity or debt for wind projects. The loans could range from personal equity lines to commercial loans using real estate as collateral. A major disadvantage of with this approach is that many farmers do not have much equity to draw on. However, there may be future opportunities for new loan programs as part of national or state farm policies. "Green funds" may soon emerge as well. Specialized private or public funds may provide grants or loans to distributed wind projects at a guaranteed, reduced rate.

Working together, the private or public sectors could design creative ways to insure a wind project's cash flow against possible technology risks and revenue shortfalls. The goal would be to reduce insurance premiums by engendering confidence in distributed wind projects and reducing the perceived risk that comes from a lack of experience with the technology and financing mechanisms.

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Chapter 3 – Utility Issues

As of 1999, U.S. utilities had gained little experience with distributed wind generation, and the role of distributed wind generation in future U.S. electricity markets remained difficult to predict. A lack of experience with wind energy, uncertainties surrounding the restructuring of the U.S. electric utility industry, and the absence of government policy favorable to distributed wind generation have contributed to an interested, but cautious attitude on the part of U.S. utilities toward this issue. Although distributed wind generation has now been successfully integrated into the utility systems of Denmark and Germany, European utilities were also initially skeptical about interconnecting distributed wind generation. From a utility perspective, distributed wind turbines present unique challenges because unlike that of most distributed generators, the power produced by wind turbines is intermittent. Even so, the interconnection of substantial amounts of wind generation to U.S. electrical distribution systems is technically feasible. For this reason, many utilities in this country are monitoring pilot wind projects and evaluating a range of technical, economic, institutional, and regulatory issues before committing themselves to owning or managing significant amounts of distributed wind generation.

Because circumstances in the United States are so different, the lessons learned from Germany and Denmark must be interpreted carefully in applying them to U.S. electric distribution systems. In Germany and Denmark, government policies provided strong financial incentives for wind development. Standards and interconnection requirements for wind generation also have been well defined and fairly uniform. In contrast, there has been no strong U.S. government policy regarding distributed wind generation, and interconnection requirements are not uniform. Consequently, technical considerations and costs are expected to be far more influential in determining its course of development in the United States than they have been in Europe.

In Europe, single turbines and small clusters of turbines are connected to a relatively strong and robust distribution system consisting entirely of three-phase lines. These strong distribution systems

Chapter Objectives

Describe the technical requirements, impacts, benefits, and limitations of integrating distributed wind generation on the electrical distribution system. Provide guidance for determining the feasibility of specific opportunities for distributed wind generation. Identify technical options that can enhance the value of distributed wind projects.

Key Questions Addressed in This Chapter

- What circumstances favor the development of distributed wind generation?
- What are the challenges to adoption of distributed wind, i.e., where is distributed wind constrained or encouraged by market, institutional, or regulatory factors?
- What are the potential benefits to utilities of adding distributed wind generation? What is the magnitude of such benefits?
- What technical opportunities exist for enhancing the benefits of distributed wind generation?
- What are the technical interconnection and power quality considerations for distributed wind generators?

were an important factor for distributed wind development there. Circumstances are different in the United States. If only minimal upgrades are required for turbines to be added to the distribution system, then adding wind generation to a U.S. distribution system may be less expensive than adding it to a transmission system. However, the majority of distribution lines in rural areas, which are most suitable for wind generation, are single phase and would require upgrading to three phase to connect wind turbines rated at more than 20 to 25 kilowatts (kW). (This turbine size limitation is based on the author's judgement.) Distributed wind generation could be limited to areas with existing three-phase lines, however, and still achieve substantial penetration in the U.S. grid.

This chapter will focus on issues of interest to U.S. utilities considering distributed wind generation. It will begin by outlining the challenges utilities will face in bringing distributed wind generation on line at a time when market conditions are changing due to industry restructuring. Economic, institutional, legislative, and regulatory issues will be highlighted. The technical challenge of integrating power produced by an intermittent resource into a utility distribution system will also be discussed. The potential benefits of distributed wind generation will be presented as well, along with a discussion of the factors that both limit benefits and make their presence more likely. The chapter will then explore such technical issues as interconnection, power quality, industry standards, and turbine design, and give insights into general technical criteria that will help locate feasible sites for distributed wind installations. The chapter concludes with a case study that investigates the potential and limitations for adding distributed wind power at different levels of grid reinforcement in Iowa.

REGULATORY CHALLENGES OF DISTRIBUTED WIND GENERATION IN THE EMERGING MARKET

Restructuring of the electricity industry is proceeding at different rates throughout the country, making the effort to define the benefits and challenges of distributed wind generation that much more difficult. Some states are fully engaged in unbundling electric utility services, while others have eschewed the process entirely. Although it is likely there will eventually be federal restructuring legislation, it is not clear when this will happen or what form this legislation will take. Rather than having a single set of well-defined rules and relationships, the market of the future will be composed of a plethora of mechanisms and customer relationships for transaction of new

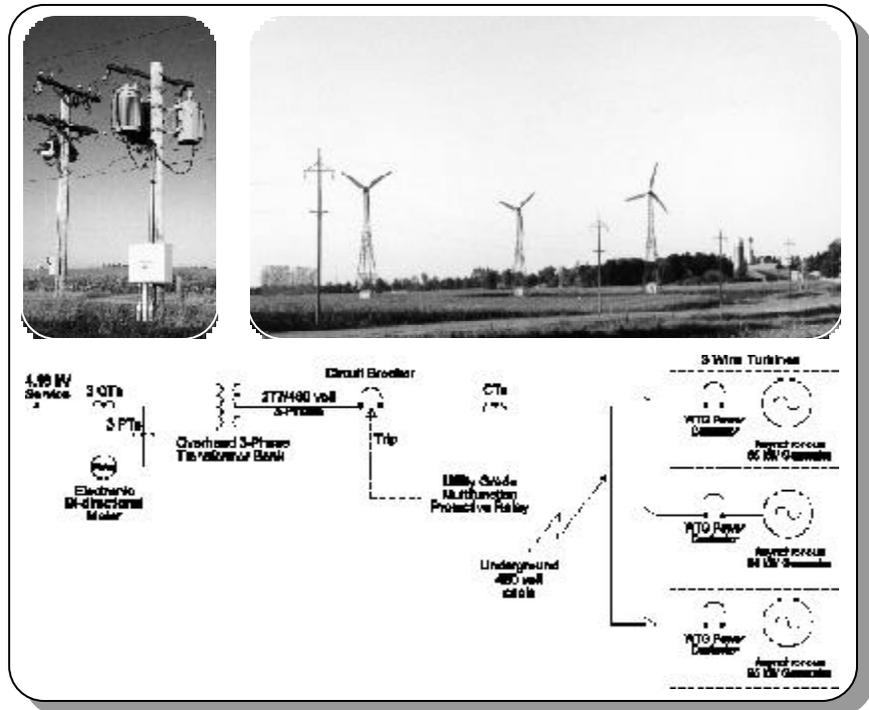


Figure 3.1 Connection of a project to the grid in Iowa. Distributed wind generation projects above about 20 kW must be connected to the grid via three-phase distribution lines, as shown above. Because most distribution lines in rural areas of the United States are single phase, they must be upgraded before being connected to large wind turbines or turbine clusters. Photo s courtesy of Thomas A. Wind.

products and services that could make distributed wind power more valuable. Such transactions will require market-based price signals, and these changing market conditions will create challenges for all supply resources. Depending on the outcome of market restructuring, there could be either enhanced or diminished opportunities for distributed wind generation.

General Regulation Issues for Distributed Generation

There are questions about how distributed generation will be valued and regulated in the future. A primary challenge in all states, whether they have restructured markets or not, will be to create regulations that are consistent with, and encourage the fair allocation of costs or benefits associated with distributed generation. For distributed generation owned by either independent power producers, who qualify under the Public Utilities Regulatory Policies Act (PURPA), or regulated utilities, the regulatory paradigm developed in the 1980s uses a utility's avoided cost of providing electricity as the basis for valuing generation additions, either central or distributed. Only generation costs are

typically included in avoided cost estimates because distribution, transmission, and ancillary service costs associated with being connected to the grid are considered relatively fixed. Avoided generation costs measure capacity and energy of distributed generation in a traditional, regulated return-on-equity, or “required revenues” framework. Because it bases the value of distributed generation on utility cost of (generation) service, this paradigm will not meet the needs of future competitive electricity markets. Further, the paradigm is not appropriate for a vertically integrated utility that employs a separate business strategy for its distribution functions. Establishing a new regulatory system that moves beyond this outdated approach will not be easy. The new system will require economic accounting approach(es) based on allocations of current asset classes to distribution system functions, followed by a market-based pricing approach that reveals the incremental costs of serving customers to all market participants. Such a pricing approach would enable distributed resources to be deployed in the locations where they are most valuable.

In states that do not plan to restructure their electric utility industry, all functions of vertically integrated utilities, including distribution, will continue to be regulated. In states undergoing restructuring, distribution companies will stand alone as regulated monopolies under the control of state utility commissions. Additional regulation from the Federal Energy Regulatory Commission (FERC) will be a part of restructured markets.

In addition to developing accounting and pricing approaches, if the goal of public policy is to encourage end users to own distributed generation, then lawmakers and regulators will have to create new incentives for utilities and customers to accomplish this. If a regulatory system can ensure that open access is the most profitable approach for a utility’s network business, then there would be opportunities for distributed generators to connect to the grid. Under such circumstances, it would be in the utility’s interest to do the analysis to identify favorable economics of specific projects. This discussion does not imply that utilities necessarily should or will be precluded from owning distributed generation. Distribution utilities and vertically integrated utilities are natural candidates to own distributed generation. They possess the network data necessary for understanding where distributed generators would provide the

highest value on their system. In addition, they are likely to be regulated by policy makers who can specify set-asides for wind. On the other hand, some regulators and policy makers may feel that allowing distribution utilities to own generation goes against the intent of restructuring. Without open competition, this type of ownership could be perceived as unfair to other power generators.

One way to meet the requirements of a new regulatory approach would be to base utility performance on a least cost provision of distribution, i.e., the lowest cost investment that would allow a distribution utility to meet its requirements. Another way would be to determine a least cost method for meeting customer needs. The method could be a distributed wind turbine, another generation source, or distribution system reinforcements to meet customer power quality, reliability, or power needs. Any system that accounts for distribution system functions, regardless of the generation source, will need strategies for identifying benefits and costs associated with those functions and quantifying them.

Another approach that has been suggested to align utilities’ profit motive with the deployment of distributed resources is a combination of performance-based rate making (PBR) using revenue caps as a regulatory framework, and geographically de-averaged buy-back rates to create price signals with incentives to both utilities and customers [Moskovitz 2000]. While not necessarily providing incentives for customer-side distributed resources, PBR with revenue caps would make utilities indifferent to them, unlike price caps, which provide strong disincentives. Geographically de-averaged buy-back rates would vary by location and would be set to reflect the location-specific cost of service. For example, in high congestion/high cost areas, rates could be set to enable utilities and customers to share the savings from the deferral of costly upgrades, while providing economically attractive returns to both parties. Further, buy-back rates would be preferable, from the political standpoint, to de-averaging all distribution prices, because, while creating proper price signals for distributed generation, the latter would also create unacceptably large differences in cost between customers.

Individual states (and eventually the federal government) will undertake the Herculean task of developing a new regulatory and market paradigm for distributed generation in general. There are

aspects of this endeavor specific to wind that will complicate these efforts even further, as discussed in the following subsection.

Regulatory Issues Specific to Distributed Wind Energy

Valuation and Accounting of Distributed Benefits

As explained in the following section of this report, the intermittent nature of the wind resource limits the existence of distributed system benefits from wind generation. Because of this fact, valuation of non-energy distributed benefits is more difficult and costly for wind than most sources of distributed generation. In addition, benefits from wind generation, when they are positive, will tend to be less than for other generation sources. There is a wide range of opinions as to what extent, if at all, an economically-feasible regulatory system can be developed to enable widespread evaluation and subsequent accounting and market pricing of distributed costs and benefits from wind generators. One thing that is clear is that the European approach of simply sweeping away all valuation issues by generously subsidizing wind projects is not likely to occur in the United States.

Distribution Wheeling Services

Charges for distribution wheeling services may play an important role in the economic equation for projects that must wheel power out of a distribution system (i.e., transfer power out using the distribution system). A distribution system owner is likely to charge a third party distributed generator, regardless of the generation type, to wheel wholesale power across its system for use on another system. Such charges could eliminate the economic value of wheeling power out of the distribution system at low load periods, which, because of the intermittent wind resource, could be a disproportionately higher source of revenue for wind projects compared to other distributed generation sources. The end result would be a decrease in the value of distributed wind compared to those other sources. For some wind projects, therefore, there may be a cost trade-off between connecting to the distribution system and installing new lines to connect directly to the transmission system. The presence of a trade-off will depend on the wind/load match, who owns the wind generation, how costs are accounted for within the transmission and distribution (T&D) systems, and whether the power needs to be wheeled or can be used within the distribution system.

Based on experience of the authors with only a few sites in the Midwest, wheeling rates quoted by utilities for use of a distribution system varied from \$0.0054 to \$0.0254/kWh, depending on utility conditions and methodological approaches.

Likewise, the authors estimated the cost of building new lines and a substation to vary between \$0.0044 and \$0.0104/kWh generated, depending upon the cost of capital and the selected amortization period. These estimates are preliminary and were developed for a project that was jointly owned by several utilities and for which power was wheeled from one system to another over weak lines. Actual rates for these or other locations would vary since they would be negotiated. However, the estimates do illustrate the potential for wheeling costs to be prohibitive. Few market rules or precedents currently exist for such distribution system transactions.

If vertically integrated utilities own distributed wind generation, there would not be a wheeling charge if the utility could use the power on its own distribution system to which the generation is connected. Likewise, such a utility may not assess a third-party project owner wheeling charges if it could use the power within its own distribution system. However, the cost may be different (higher or lower) for moving power from the transmission system compared to moving it from a distributed generator. It is not clear who would benefit or be charged for this difference. The impact of this difference on the value of the distributed generation would depend on how the utility is structured, physical characteristics of the different power paths, and what the regulatory requirements are. Most likely, the treatment of this valuation and billing issue will vary between states and utilities.

To avoid wheeling charges in a restructured market, a possible option for distributed project owners might be to sell excess electricity to power suppliers serving customers on a distribution system. The power suppliers would use the purchased distributed generation to displace power otherwise obtained through the transmission system. In this case, wind power's value would theoretically be based on the wholesale value of the displaced generation plus or minus any change in cost for use of the distribution system. Wind project owners could realize additional value from the sale of renewable energy credits if such a market were to emerge.

Ancillary or Other Services

If transmission and distribution charges for rural areas, which are usually more expensive to serve, are unbundled as a result of restructuring, the impact on the value of distributed wind projects could vary widely. In general, geographic de-averaging of costs and rates would benefit distributed generators with respect to central station plants. However, it may be that the majority of distributed wind sites would incur disproportionate costs compared to other distributed generators for non-energy services required by the wind plant.

Ancillary services support the basic services of generating capacity, energy supply, and power delivery [Hirst and Kirby 1996]. They may include:

- scheduling, system control, and dispatch;
- regulation for minute-to-minute real power fluctuations;
- reactive power supply and voltage control;
- load following for slower power fluctuations than under the regulation category;
- spinning reserve for immediate response to unexpected loss of generation or transmission;
- supplemental reserve for a slower response (10 minutes) than spinning reserve provides for unexpected loss of generation;
- voltage support throughout the transmission system (not at individual customer sites); and
- energy imbalance, an accounting service that corrects for differences between actual and scheduled energy transactions.

FERC does not currently include load following. There is also widespread disagreement over the appropriateness of including energy imbalance [Kirby 1999]. A host of factors determine the cost or benefit of each of these services to any wind plant.

It is not clear how these services might be treated economically in the future. The penetration level of wind projects, the status of restructuring, and the general philosophy of how to assess customers for ancillary services could all influence how states deal with the issue of wind [Kirby 1999; Porter 1999]. For example, in states where no restructur-

ing occurs and low levels of wind power penetration are present, there may be no effort by utilities to consider ancillary service costs for individual projects. States with restructured markets would be more likely to evaluate wind projects in terms of ancillary service costs, especially if wind begins to penetrate the market in any significant amount.

In an unbundled market, wind plants will likely have to buy more ancillary services than they will sell [Kirby et al. 1997]. Therefore, it is reasonable to expect that there could be net costs for these services. In theory, ancillary service costs and benefits for distributed wind projects should be similar to those for larger wind farms. However, the cost of evaluating them is relatively constant for any size project, so they will be proportionately higher for distributed projects. This could make such evaluations economically impractical. In practice, costs will depend on how wind power is treated. For example, if wind power fluctuations on a scale of minutes are treated as a power regulation problem rather than as load following, costs will increase. On the other hand, a wind resource could be shown to “fail” more slowly than a fossil-fueled generator if the wind decreased over a scale of minutes instead of seconds. In this case, wind might not require as much spinning reserve and could rely more on cheaper supplemental reserves.

THE BENEFITS OF DISTRIBUTED WIND GENERATION

Because generation from wind turbines is often unpredictable on a short-time scale, distributed wind installations will provide significant distribution system benefits only in limited cases with a good match between a highly predictable wind resource and the system load or other specific requirements of the electrical system. More often, wind will only provide modest-to-no system benefits and may require reinforcements to the distribution grid. In addition to the correlation between wind and load, the extent to which one or a combination of benefits might be present, if at all, at a given location depends upon a number of factors, including:

- wind generator type, reliability, and wind turbine power output curve;
- number of turbines and their location on local utility distribution systems;

- wind resource characteristics;
- characteristics of the subtransmission and distribution systems near the proposed wind site;
- the ability of the local distribution system to meet customer load and service requirements, including voltage, tolerance for outages, and peak power demand;
- transmission system characteristics, in particular reliability criteria and loading levels;
- generation system characteristics, including generator types, installed capacity, native load shape, and growth;
- ownership of turbines, generation, transmission, and distribution systems (i.e., vertically integrated utility, distribution utility, utility customer, regulated versus unregulated power company); and
- size of demand charges.

Because of wind's intermittent nature, wind generation projects will usually require individual analysis to determine the presence and extent of distribution system benefits. A key concern is that the cost of performing such detailed engineering cost trade-off studies will prohibit them from being conducted on a wide scale. While a large experience base could provide the "rule of thumb" information needed to simplify such analyses and reduce the cost of making economic assessments, unless such a knowledge base is developed, the costs of such analysis may be prohibitive. It is not clear if this circular problem will be resolved. A further potential concern is that project owners will find the evaluation of distributed benefits more difficult and expensive if they do not have access to utility system data.

Maximizing Benefits from Distributed Wind and Minimizing Costs of Electric System Impacts

Conditions required for the accrual of generation, transmission, or distribution system benefits, and the magnitude of benefits associated with installing distributed wind, are site-specific. In very limited instances, distributed wind generation may add significant electrical support or serve additional

loads. For example, the addition of a single turbine or small cluster of turbines at a specific location with a good wind resource could delay or eliminate the addition of distribution facilities, reduce losses, and provide voltage support on weak distribution lines. This benefit will depend upon the correlation or match between the wind generation and the load. For example, if a statistical analysis indicates that there is a relatively high probability of the wind generation being 10% of nameplate rating or higher during high load periods (a period such as the top 5% of the load hours), then the utility might decide to rely on 10% of the generation being available during the peak. The selection of a probability level for a given amount of wind generation being on line can probably be related to the other distribution reliability design standards used by the utility. Such existing standards might include customer outage probabilities, repair times, and frequency and duration of emergency overloads. Again, many feel there is a low likelihood that such analysis can be conducted on a regular basis because the cost would be prohibitive. Establishing a value for benefits is further complicated by the fact that there is no standard approach to making this type of valuation.

When distributed wind projects are on-line, some operating reserve requirements can be imposed on the rest of utility system generation. Operating reserve requirements consist of spinning and supplemental reserve, which typically vary from 3-7% on interconnected U.S. utility systems. In a competitive environment, the costs of providing additional spinning reserve may be reflected in lower value for distributed wind projects because they are not dispatchable. However, if the distributed wind generation is relatively small compared to the control area load, then the variations in wind generation output will likely not make any difference in the utility's operating reserve requirements. If the wind generation is larger, perhaps greater than a couple of percent of the control area load, then the addition of even a few minutes of storage could decrease its tendency to increase operating reserves. However, the cost of this storage would likely be greater than the cost of the extra operating reserves. Adding small amounts of energy storage is also a way of smoothing out instantaneous drops in wind power output fluctuations, while simple controls can limit unwanted instantaneous power increases. Since such power fluctuations can increase area and frequency regulation requirements, adding storage and/or controls could

reduce the costs where excessive area and frequency regulation requirements may incur penalties in future restructured markets.

Another method of providing output control would be to develop a hybrid distributed project with wind turbines and a gas-fired micro turbine (or other fossil-fueled generator). Using a hybrid wind system or adding storage would increase transmission and distribution benefits for specific distributed wind projects in a competitive environment. If a nonregulated power producer located a distributed wind project with output control in the right place, significantly higher facility deferral benefits could accrue to local transmission and distribution companies. Adding control to the distributed wind project could also enhance local area power quality. For example, a small amount of storage



Figure 3.2 Waverly Light and Power 80-kW turbine shown here with Waverly's Manager Glen Cannon, who championed the project. Waverly Light and Power's 80-kW Zond Z16 turbine was the first in Iowa to be utility owned and operated. The utility's success in demonstrating the technical feasibility of interconnecting distributed wind generation led to a new 2.25-MW project in Algona that is owned and operated by seven Iowa municipal utilities. Photo courtesy of Ken Formanek.

could provide ride-through capability for voltage sags and momentary outages, increasing local system reliability. The owner of such a system would have to weigh the added costs of installing storage against the added return it would provide in the competitive marketplace.

Finally, apart from the issue of whether non-energy benefits can ever be calculated economically, the value of distributed wind projects that do have positive non-energy benefits could be increased by advances in wind forecasting techniques that would allow wind speeds to be predicted on the time scales of minutes, hours, and days.

Defining and Identifying Benefits

Although non-energy benefits from distributed wind turbines will be limited in occurrence and perhaps unlikely to be evaluated for most projects due to the cost involved, it is useful to define the specific benefits being referred to. This section defines potential benefits and provides guidance to help developers, electricity providers, or others identify situations where such benefits are most likely to be present. The presence and size of most of these benefits is dependent on a combination of various conditions, such as size and location of the wind turbine on the distribution system, size and location of the load on the system, and others. The technical appendix for this report presents several scenarios of different turbine placements on a distribution system, and includes electrical diagrams and detailed discussions for each scenario to help elucidate the impact of various conditions on the feasibility of placement and the occurrence of potential benefits to the electric system.

Generation System Benefits

The magnitude of potential generation system benefits varies among utilities in different regions of the United States. Generation system benefits include:

Energy Displacement Benefits. These benefits are calculated by comparing utility operating costs, including fuel requirements, with and without wind generation.

Capacity Value and Demand Charge Reduction Benefits. From the utility point of view, capacity value is determined on a site-specific basis by taking account of historical data regarding generation availability; peak-load

demand and how well this demand correlates with anticipated wind power generation; and planning criteria for power generation. From the point of view of distribution utilities or customers who incur a demand charge, these benefits are associated with the reduction in the amount they are charged by the utility due to the utility's calculation of increase capacity value.

Transmission System Benefits

Transmission system benefits are not usually significant for small amounts of distributed wind generation. They include:

Transmission and Subtransmission Facility Deferral Benefits. These benefits generally apply to heavily loaded facilities or facilities in areas that can have low voltage. They are location-specific and may be difficult to identify for small amounts of distributed wind generation.

Transmission Loss Reduction Benefits. Wind generation will reduce transmission system losses in almost every case. Loss reductions typically range from 3% to 7% of the wind power generated, depending upon the transmission system. An increase in transmission losses could conceivably occur if a substation with the distributed wind generation were very close to an area with a large amount of other generation that exports power on the transmission system.

Increased Load Serving Capability of the Transmission System. If the transmission system needs voltage support in the area, or if it is near its thermal capacity, then adding wind generation on the distribution system will reduce the net load level. Again, the benefit would depend on the probability of there being wind generation during the critical high load periods.

Distribution System Benefits

Distribution system benefits are directly related to the configuration of the distribution system, loading, and the physical location of the wind turbines on distribution feeders. These benefits include:

Increased Load Serving Capability of the Distribution Line. Adding wind generation to a distribution line that is thermally or voltage-

drop constrained could potentially increase the amount of load the line could serve. This benefit would depend on the probability of there being wind generation during critical high load periods. The anticipated wind generation during these periods would equate to the amount of additional load that could be served. If there is even a small chance (5% or less) that there will be no wind generation during high load periods, then distribution system planners are not likely to increase the load serving capability of the line. The maximum load serving capability of the substation transformer would similarly be affected.

Distribution Loss Reduction Benefits. If the amount of generation added (nameplate capacity) in a specific location is less than or approximately matches the load, then distribution system losses will probably be reduced. The amount of loss reduction will depend upon the correlation of load and generation patterns. If the amount of generation at a location exceeds the load at that location and beyond, then distribution losses could increase. A site-specific engineering analysis is necessary to determine the impact on distribution line losses.

Distribution Voltage and Power Factor Correction Benefits. These benefits accrue when distributed wind projects (employing turbines with either variable speed or synchronous generators with active voltage control) can improve distribution system voltage by supplying real or reactive power and by providing power factor correction on a minute-to-minute basis.

Distribution Facility Deferral Benefits. These benefits are the least likely distribution system benefits, but can accrue when wind projects can be strategically located throughout a heavily loaded or voltage constrained distribution system or installed at the end of a feeder to reduce peak-feeder or distribution substation loads. Adding wind generation to one of the circuits on a heavily loaded substation could potentially defer the need for increasing substation transformer capacity. Again, this benefit would depend on the probability of there being wind generation during the high substation transformer loading periods.

Project Feasibility Criteria

When conducting an analysis of the potential for benefits from distributed wind plants, one must consider many variables, including turbine size, location of the turbine(s) on the distribution system, size and location of load, and others. The following guidelines should be considered when assessing the preliminary feasibility of a specific distributed wind project. Site-dependent characteristics may change these somewhat, and a qualified engineer should be consulted to verify final feasibility.

Distance from a three-phase line. To minimize installed costs, a three-phase line should be within about 0.8 km (0.5 mi) of the proposed location.

Amount of electrical load served by the distribution line at and beyond this location.

The minimal amount of wind generation that can be added at a specific site is often equal to the load served by the distribution line at and beyond the wind turbine. However, power quality considerations may constrain the placement of wind generation to within 4 miles or less of the substation.

Electrical strength, or short-circuit megavoltamperes (MVA), of the line. Wind generation equal to 5% of the short-circuit MVA can be added at a site without creating unacceptable power quality impacts. Generation up to 10% of the short-circuit MVA can be added by using certain types of generator designs and operating procedures. Wound-rotor generators and variable-speed turbines can provide better power quality than induction generators. If turbine operation can be curtailed at certain critical times that might cause loading problems or excessive voltage rise on the distribution system, then its connection to the distribution system could be more acceptable. The amount of voltage rise may limit the cumulative amount of generation added to a distribution line. Controlling the power factor of the generation can be a tool to limit voltage rise on the feeder.

Distribution conductor size. The amount of generation that can be added on a distribution line is constrained by the thermal capability of the conductor between the substation and the proposed location. The thermal capability of a conductor will vary with wind speed and power generation.

Distribution line voltage regulators. If line voltage regulators are located between the substation and the wind generation, then they must not be overloaded by the additional wind power generation. They must also be able to work properly with reverse power flow. Since voltage regulators are typically located beyond four miles from the substation on rural lines, it is unlikely large wind turbines could be located beyond line voltage regulators due to power quality concerns. Regardless of where the turbines are located relative to voltage regulators, wind variability could potentially cause excessive voltage regulator operation, leading to increased maintenance costs.

Size of the substation transformer. The total amount of generation added to all of the distribution feeders being served by the transformer is limited to the size of the substation transformer plus the minimum expected customer load level. If wind generation can be curtailed during low-load periods, then some additional generation could be added without overloading the substation transformer. Small substation transformers, i.e., 2.5 MVA or less, will reduce the short-circuit capability, which in turn requires turbines to be located near the substation. For substations with transformer sizes of 1.5 MVA or less, turbines larger than about 750 kW must have especially soft starting characteristics to avoid causing excessive voltage dips on the distribution system during turbine start-ups. Small turbines could easily be added in such situations without the same concerns.

INTERCONNECTION AND POWER QUALITY CONSIDERATIONS

The installation of significant amounts of distributed wind generation will have substantial impacts on local utility distribution systems and subtransmission facilities connected to distribution substations. These impacts will be encountered at the distribution level long before the local wind penetration reaches a level that seriously affects a utility's bulk transmission facilities. Figure 3.3 shows the various elements of the transmission and distribution system. Connecting single wind turbines or small clusters of turbines to existing electrical distribution lines is more economical than building new lines to collect the power. However, there are limitations to the amount of

wind generation that existing distribution lines can accommodate. The limitations stem from the design of the distribution networks and from the design of the wind turbines themselves.

The design of distribution networks reflects the needs of electricity customers in a given area. If the electric load density in the area is low, as would be the case for a rural area containing small farms, then the distribution system will have limited capacity for adding any type of distributed generation, including wind turbines. However, if there are several large electricity users, such as commercial or industrial customers, then the distribution lines will more likely be able to accommodate larger amounts of wind generation.

Rural substation transformer size and power quality requirements are likely to limit the amount of wind generation that can be added to a specific distribution line to between 100% and 125% of the load the system was designed to serve. Large wind turbines (rated at hundreds or thousands of kW) can often be connected to the rural distribution lines in an amount about equal to the substation transformer capacity, assuming there is no other distributed generation and the wind turbines are relatively close to the substation. Often, the new wind generation will not require significant system reinforcements. Depending upon the transformer size, the feeder wire size, and the turbine design, the turbines will probably have to be within about 1.6 km to 4.8 km (1 mi to 4 mi) of the substation. However, the exact location of the distributed generation may be constrained due to potential power quality concerns. If power quality impacts are too high, or if the penetration level of wind turbines exceeds the allowed peak-load levels on the substations, then distribution system reinforcements could be required. Such improvements could include larger substation transformers, larger substation circuit breakers, or larger wire on the feeder. A case study that investigates how these issues affect the potential for interconnecting distributed turbines in a typical region in Iowa is presented later in this chapter.

The most important consideration for adding wind turbines to a distribution system is the electrical strength or stiffness of the distribution system at the proposed point of interconnection. Strength refers to the ability to deliver or absorb power. The requirements, benefits, and penetration limitations of distributed wind generation depend on whether

a specific project is connected to a strong, thermally limited distribution system or a weak, voltage-limited distribution system. A strong 13-kV (kilovolt) system would be expected to contain feeders less than 6.7 kilometers (km) (4 miles (mi)) long with relatively large conductors over most of the feeder length. A weak system would contain longer feeders with relatively small conductors for most of the distance. A strong distribution system can absorb significant amounts of intermittent wind generation with relatively modest impacts on the quality of power. Most rural distribution systems in the United States are voltage-limited.

Ideally, power generators should produce constant, stable, harmonic-free power. However, the power output from a single wind turbine is usually quite variable. Power fluctuations occur during wind turbine switching operations, such as when they first come on-line or go off-line, and when they switch between a low-speed generator and a high-speed generator. In addition, as the blades rotate, the power from blades varies due to changing wind speeds at different heights above ground, and when the blades pass the tower. The use of variable speed turbines with power electronics technology has gone a long way toward eliminating this problem. The variable nature of the wind is another factor preventing wind turbines from producing constant power. Gusty wind conditions can cause the power output of a single turbine to increase by 50% of the rated power within a span of a few seconds. Little can be done to reduce this variability without some type of output control.

Turbine Design Considerations

Maintaining good power quality is a significant hurdle for adding wind generation to the existing distribution system. The choice of generator will affect power quality and the availability of reactive power. For example, some wind turbines equipped with asynchronous generators can draw a significant amount of reactive power from the grid during start up, causing a voltage dip. In contrast, variable-speed turbines equipped with power electronic converters can reduce the voltage dips during start up. Turbine design is important in determining where large wind turbines can be connected on an existing feeder to avoid power quality problems. Turbines with power electronics (that create very soft starts) or voltage control can be located farther from the substation.

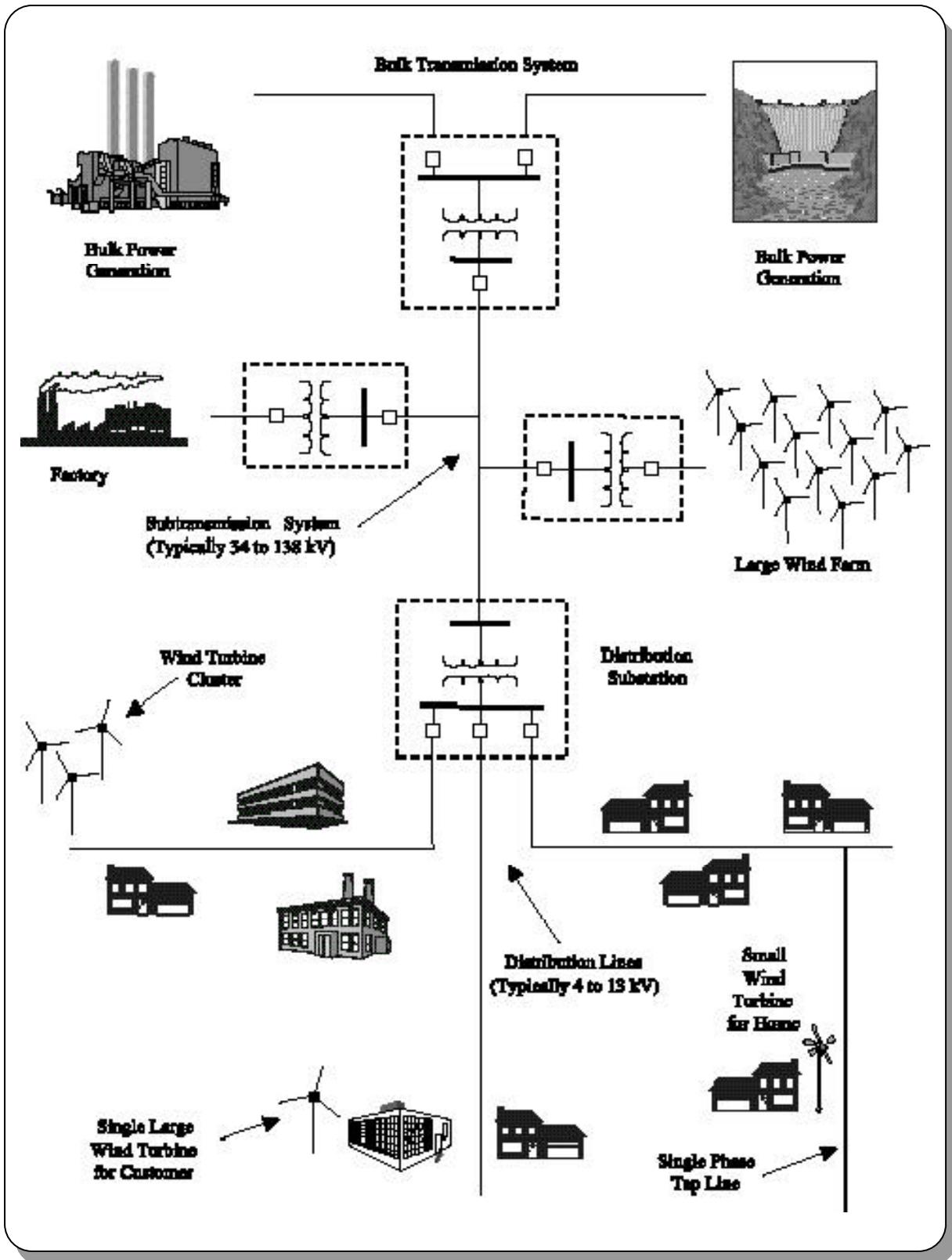


Figure 3.3 Electric power system functional diagram.



Figure 3.4 Iowa Joint Municipal Utility Project 3 x 750 kW. As part of the 2.25-MW Iowa Distributed Wind Generation Project, researchers are testing the ability of advanced turbine technology to minimize power quality problems on a weak distribution system. Photo courtesy of Thomas A. Wind.

becomes a design consideration that adds cost to the wind turbine. In general, the more sophisticated turbines and controls reduce the impact on power quality, and continued reductions are expected with better turbine designs. These improvements will enable more wind capacity to be installed on distribution systems. The trend toward larger sized wind turbines, however, will tend to increase power quality impacts if the turbines are connected to the distribution system.

Wind turbines can introduce voltage flicker, harmonics, or raise the voltage on a distribution system. Voltage flicker, which is caused by variations in line voltage, can cause a noticeable flickering of lights that often results in customer complaints to the local utility. This is not common for distributed wind generation, but it could occur in specific situations on weak distribution lines. Most wind turbines also have some level of distortion, or harmonics, in the electrical power they generate, either during start up or normal operation. Harmonics on a distribution line can cause sensitive electronic equipment to malfunction. The number of wind turbines that can be added to a distribution line may be limited if wind generation causes a voltage rise greater than about 2% on the line. While there is no universal standard for a 2% limit, this number is consistent with the experience with large numbers of turbines in Denmark and German, and is reasonable for U.S. systems as well.

Voltage flicker and harmonics are influenced by the design of a wind turbine. Asynchronous generators with fixed-pitch blades generally produce the greatest variability in the power output and thus have more potential to cause voltage flicker on the distribution system. Unfortunately, asynchronous generators are also relatively inexpensive. Turbine designs that smooth out power fluctuations using blade pitch control, wound rotor generators, or electronic power converters will be less likely to cause voltage flicker. However, if a wind turbine uses an electronic power converter, it will create some level of harmonics. Controlling the level of harmonics

Interconnection Standards

Utilities have the responsibility of maintaining a safe and reliable system and of maintaining power quality. For this reason, individual utilities must have interconnection requirements for wind turbines (and other distributed generators). However, the requirements have not been standardized and vary according to the size of the generator. For rural utilities, existing interconnection requirements were typically set to accommodate the operation of backup emergency generators at factories and farms. Larger utilities usually had more extensive requirements because they typically had more interconnections to customer-owned generation.

One of a utility's primary concern is to ensure that the distributed generator cannot inadvertently energize utility lines when they are off-line and being worked on by utility personnel. Therefore, protective relays are required to trip the turbines off-line for any abnormal electrical system condition. In addition, distributed wind turbines will have separate protective relays or built-in equipment to disconnect the wind turbine from the utility's distribution system during abnormal operation. Abnormal conditions include high or low voltage, high or low frequency, and high or unbalanced currents. The source of these abnormal conditions could be a utility system fault that needs to be isolated and de-energized, or it could be a malfunctioning wind turbine generator.

Because of a wind turbine's intermittent and fluctuating power output, it can cause more power quality problems on the distribution system than

other distributed generation. Because of their small size, wind turbines smaller than 100 kW are less likely to cause power quality problems in most distributed applications. Thus, interconnection requirements for these turbines could be very simple. However, larger wind turbines can cause power quality problems on a distribution system, particularly if the turbines use constant-speed generators without soft starting power electronics. At present, because manufacturing design standards and certification do not exist, utility engineers must perform detailed evaluation of each proposed installation of large turbines to determine whether power quality impacts would be acceptable. In conjunction with standards, simplified evaluation procedures, but not any single or required approach, could reduce the costs for evaluation of interconnection requirements and impacts.

An industry standard and application guideline, coupled with an associated design certification process, would help in determining if a proposed wind turbine installation will cause power quality or operating problems on its system. Such a standard could also address turbine design, interconnect equipment, and procedures for connecting the turbines to distribution lines. The Institute of Electrical and Electronics Engineers (IEEE) has started to develop a standard that addresses electrical safety, equipment protection, and power quality.

Manufacturers, utilities, and turbine owners would all benefit from a standard. Manufacturers could use it with an application guide to design a wind turbine's electrical interface equipment. With a certified turbine design, the utility's interconnection evaluation process would be simpler and less expensive. With adherence to the interconnection standard, little, if any, additional electrical interface equipment would be needed to connect the distributed generation to the electrical system. Customer-owners of distributed generation would benefit from the proposed standard as well. The customer would use a simple standardized application form for interconnection that would provide all of the information needed by the utility. The application would supply information from the manufacturer as required by the new interconnection standard.

Interconnection Issues in Denmark

In evaluating interconnection requirements for distributed wind generation in the United States, it may be helpful to look at Denmark, which has more than 1000 MW of distributed generation. Hundreds of turbines with an average rating of 10 to 50 kW were installed in Denmark in the late 1970s and early 1980s. Individual machines were connected directly to the 230/400-volt (V), three-phase grid. By 1990, the average size of grid-connected wind turbines in Denmark was greater than 200 kW—the upper limit of what could be connected to the 230/400-V grid.

As turbines increased in size over time, they either became too large to connect to the low voltage grid or caused unacceptable voltage dips and flicker. Utilities solved the problem by connecting the bigger turbines to the 10-kilovolt (kV) grid. As turbines continued to increase in size, they began to affect the power quality on the 10 kV grid. Depending upon where the wind turbines were located, costly system reinforcement was required. Solutions that have been used include: installation of a dedicated feeder several kilometers long to connect the wind turbines directly to the 60/10-kV substation; and replacement of an existing underground cable with a larger capacity cable.

Because of the possible need for expensive system reinforcements, the location of a large wind turbine could have had a significant impact on interconnection costs. However, the Danish government wanted to encourage widespread ownership of wind generation. Therefore, in 1992, the government set up a pool of money funded by all Danish electrical customers to reimburse the utility for all interconnection and system reinforcement costs from the high side of the wind turbine generator step-up transformer back to the utility. As a result, all wind turbine owners had nominal and comparable interconnection costs.

Interconnection of Distributed Turbines in Denmark: A Case Study

Gravers Kægaard is a successful pig farmer in Ringkøbing County, Denmark. He and two other farmers own a cluster of three Vestas 660-kW turbines connected to a 10-kV 3 phase distribution line. One of the other farmers owns the land on which all three turbines are located. Kægaard's turbine produces approximately 1,600 MWh of electricity a year. His income from the sale of electricity is equal to about one-third of his proceeds from pig farming, which is a highly profitable industry in Denmark.

The wind project began when Danish turbine manufacturer Vestas approached the land owner with an offer. Once he decided to go with Vestas, the other two owners were solicited. All three had the option of using another manufacturer, but they had to decide quickly. If Vestas located other buyers, Kægaard and the others would lose their opportunity. The wind project was like the U.S. real estate market, in which sellers can play potential buyers off each other for leverage. After checking with one other company for a price comparison, and confirming Vestas' wind resource estimates with the Wind Turbine Owners Association, Kægaard decided to sign with Vestas. The turbines were up and running 15 months later in January 1998.

Like other turbine owners, Kægaard was responsible for providing electrical facilities for interconnection. He constructed an enclosure near the turbines that contains a 690-volt circuit breaker, an 800-kVA (kilovoltampere) 0.69/10.5-kV step-up transformer, 80-amp high voltage fuses, and two meters, one for recording energy generated and the other for recording energy used by the turbine while it is off-line. The circuit breaker is used to disconnect the wind turbine from the grid for line maintenance or emergencies. It has a standard industrial time-overcurrent tripping mechanism.

The three turbines are located about 700 m (770 yards) from an aging 10-kV overhead line made from very small 35-kcmil (thousands of circular mils of area) copper wire. Using national standards for calculating power quality, the local utility, RAH, determined that the older overhead line was inadequate and needed to be replaced with a new 10-kV, 150-kcmil cable. The utility installed 5 km (3 mi) of new cable, which became a main feeder from an existing 10-MVA 60/10-kV substation at Spajald. The wind turbines, which were about 2.5 km (1.55 mi) by cable from the Spajald substation were tapped on this new 5 km cable. The substation has a peak load of 5 MW. RAH received about \$140,000 for its distribution system reinforcements from a national fund dedicated to connecting wind turbines to the grid. RAH used some of the money to purchase additional capacitors for the system to compensate for the three wind turbines.

The turbines could be connected to a different substation 6 km (3.7 mi) away from the turbines, if part of the new cable or the Spajald substation was out of service for maintenance. However, a section of this alternate path has small wire, which meant wind turbine operation would likely cause excessive voltage rise along the long feeder to the other substation. Therefore, when the new cable or substation needs maintenance, RAH plans to shut off the turbines with a circuit breaker. It is common in Denmark for alternate feeders to be inadequate or too long to allow clusters of wind turbines like these to operate normally.



Figure 3.5 Turbine and typical electrical equipment enclosure on a Danish farm. Like other turbine owners, Gravers Kægaard was responsible for providing electrical facilities for interconnection. He built the enclosure on the right to house a circuit breaker, step-up transformer, fuses, and meters for a three-turbine cluster. Kægaard uses the door on the left to gain access to electrical controls and a ladder inside the turbine tower. Photo courtesy of Thomas A. Wind.

IOWA CASE STUDY

Circumstances in Europe are quite different from those in Iowa, where a few utilities are just now beginning to investigate distributed wind generation. A case study of a region in Iowa was developed to investigate the potential and limitations for adding distributed wind power at different levels of grid reinforcement to a typical area of the Midwest. The technical appendix to this report contains a detailed discussion of this case study. The study uses actual information and data from a 1942-square (sq.) kilometer (750 square mile) area in Iowa. There are eleven small towns, with a combined population around 13,000, with another 4,000 people living in rural areas. The land is flat to gently rolling with about 91% of the area planted in feed grain crops. There are 1545 km (960 mi) of 12.47-kV and 13.8-kV distribution lines in the rural areas. Of this total, 57% are single phase, 10% have two phases, and 33% are three phase. There are 15 substations fed by a 69-kV network, and a typical rural substation has a 2.5-MW substation transformer size. A 161-kV line and substation supplies the area with its power needs. There is a total of 15 MW of diesel peaking generation in two towns in the study area that is operated during the summer peak. The peak electric loads and the annual electric energy consumption was estimated for the area to be 34 MW in the summer and 32 MW during the fall corn drying season. Annual energy use was estimated to be 160,000 MWh in 1998. Detailed wind resource data was obtained from the Iowa Wind Energy Institute in Fairfield, Iowa. The wind resource in the area is fairly uniform, with the majority of the area having average annual wind speeds between 7.4 and 7.7 meters per second (m/s) at 50 meters height.

After plotting all power lines and distribution system equipment in the region, a preliminary engineering evaluation was made of the ability of the distribution systems to accommodate the addition of large 750-kW wind turbines. Such a turbine would generate about 2.0 million kWh per year. The evaluation

showed that more than the local load could easily be electrically accommodated by the distribution system. The case study also revealed that sites where wind generation may have the potential to delay or eliminate distribution system improvements were limited and site-specific. Any specific site with potential benefits requires a detailed engineering analysis to confirm their existence and size. In some instances, large wind turbines (with low power quality impacts) could be added to the distribution system with essentially no system reinforcement costs, while other sites would require system reinforcements such as larger substation transformers and 3-phase line extensions. In general, the main three-phase feeders are adequately sized and are generally in a good state of repair, so added wind generation at some nominal level would have minimal effect on future investments in feeders.

Three levels of wind generation penetration associated with three increasing degrees of system reinforcement were determined for the study. The first level was based on making no system reinforcements or line extensions to the distribution system. The standard interconnection configuration for each wind turbine was based on having a generator step-up transformer, up to 1/4 mile of underground primary cable, and a set of fuses for connection to the distribution line. This cost for interconnection was assumed as the base or reference cost of interconnection. In this level of penetration, wind turbines would be located within 1/4 of a mile of a 3-phase line or another wind



Figure 3.6 Typical land for distributed wind generation case study in Iowa. The case study explored the ability of the existing distribution system to accommodate the addition of large (750-kW) wind turbines. Photo courtesy of Thomas A. Wind.

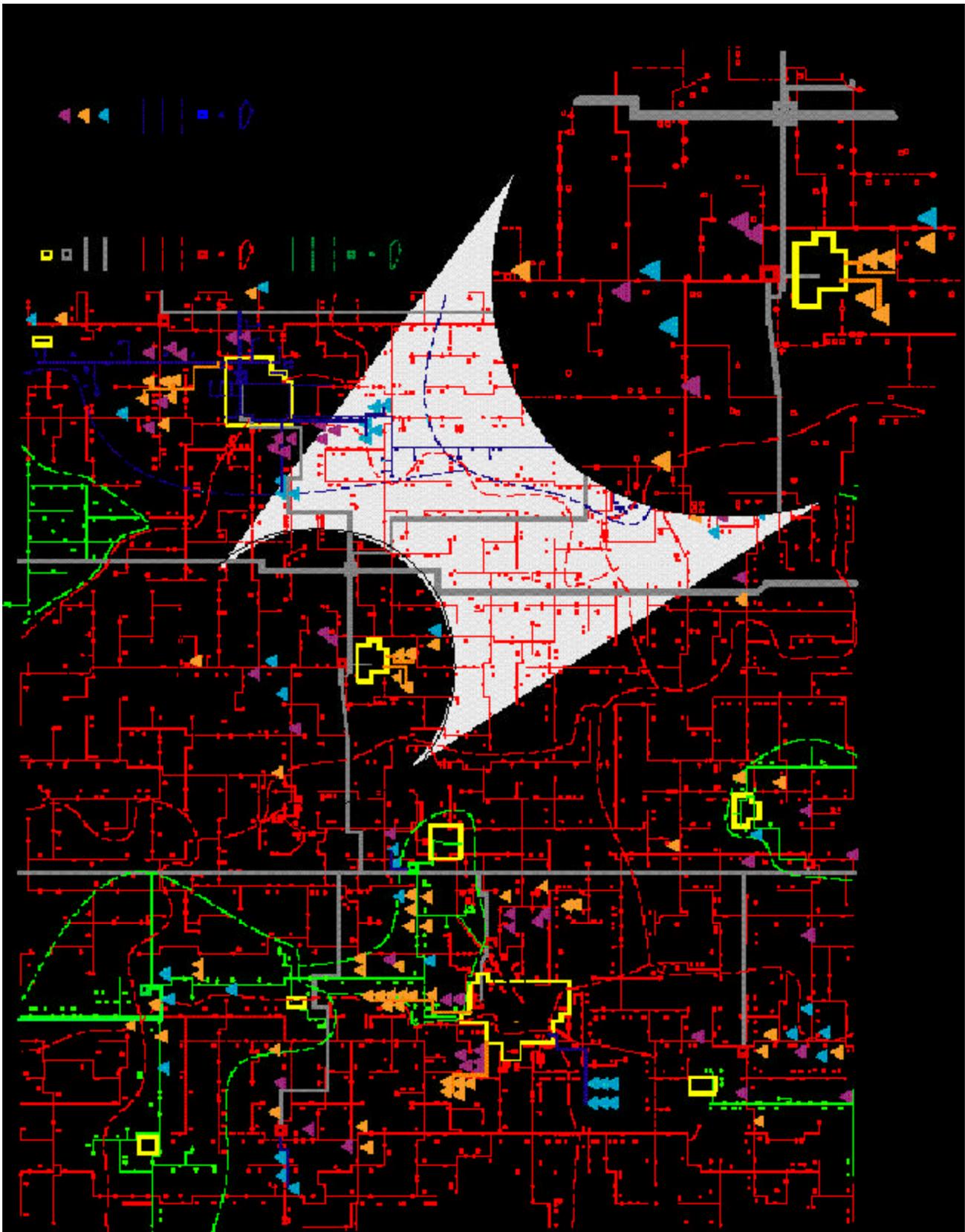


Figure 3.7 Electrical lines, customers, and wind turbine placement in Iowa Case Study area.

turbine, since no reinforcement costs were allowed. Some minor equipment changes and adjustments would likely be required by the utility, including new voltage regulating relays at the substation, evaluation of protective relay and reclosing relay settings, and evaluation of operating and sectionalizing procedures. The cost of these changes and adjustments is relatively modest.

Two higher levels of penetration were determined by estimating two increasing levels of investment in system reinforcements (using engineering judgement of the principal author of the case study). These investments were typically for larger substation transformers and regulators, higher capacity substation reclosers or breakers, and extensions of 3-phase lines from the towns outward into the rural areas to connect with wind turbines. Each substation was evaluated to determine how much wind generation could be added to its feeders without causing significant operating problems or adversely affecting power quality. The wind generation added in the case study was assumed to have very soft starting characteristics, typical of a those with variable pitch and a wound rotor generator.

Figure 3.7 shows distribution and transmission lines and substations in the study area, and indicates where various turbines could be added (regardless of their cost effectiveness) for each of the three different degrees of system reinforcement. Table 3.1

details the amount of capacity that can be added at each degree, and the corresponding incremental and cumulative costs for the reinforcements.

The study showed that adding nominal amounts of distributed wind generation could reduce electrical losses. Although the purpose of the case study was not to determine if distribution or transmission system facilities could be deferred, a preliminary assessment showed a possibility for distributed wind generation to delay future transmission facilities for voltage support to the case study area. However, a more detailed analysis would be required to verify the likelihood of this possibility. In addition, in one specific location of the case study area with projected load growth, there also appeared to be potential for a few strategically located wind turbines to delay the future addition of distribution system equipment. Again, a more detailed analysis would be required to verify this. The analysis would have to show a large enough correlation between wind generation and the peak load period to prove that there is a good likelihood that at least some wind generation would be on-line during peak load times. Further, this amount of "likely" generation, i.e., generation that is highly correlated with the load characteristics, would have to be sufficiently large that existing substation transformers would not have to be increased in size in the event of future load growth. Finally, the case study results suggested that wind generation could reduce substation transformer loading.

Penetration/ Reinforcement Cost Levels	750-kW Turbines Added		Reinforcement Cost For Each Level (\$/kW)			Average Reinforcement Cost For Cumulative Capacity (\$/kW)
	Number	MW	Minimum	Maximum	Average	
Level I (least expensive)	48	36	\$2	\$20	\$5	\$5
Level II (moderately expensive)	62	47	\$27	\$105	\$61	\$36
Level III (fairly expensive)	41	31	\$38	\$178	\$115	\$58
Totals	151	114	---	---	---	---

Table 3.1 Potential distributed wind capacity penetration and associated costs for increasing degrees of distribution system reinforcements.

In general, of the 151 wind turbines that could potentially be added to the distribution systems in the case study area, only a few of them have the potential to defer distribution facility additions. Typically, more distribution system reinforcements would be required, rather than deferred, to accommodate the higher penetrations in Levels II and III. It is more likely that the addition of a nominal amount of wind generation (similar to the amount in Level I) in the case study area will defer additional transmission facilities, rather than distribution facilities. The addition of smaller wind turbines avoids most of the power quality concerns caused by larger turbines. Smaller turbines would not be constrained to locations close to the substation. They could be located at the end of the feeders, in particular if they were sized to meet the customer's energy needs.

The study demonstrated that distributed wind generation can provide economic benefits to utilities, land owners, and turbine owners. However, the benefits varied depending on who owned the wind turbines and the level of penetration of wind generation in a given area. The overall project economics depend in large part upon quality of the wind resource at the specific location. Without a good wind resource, even if the wind turbine provides distributed benefits, it may be more economical to simply add the needed new distribution facilities and install the wind turbine somewhere else with a slightly better wind resource. Similarly, a large wind turbine might not be located in the most economic place, even if it could be connected to the existing distribution system with no added cost. If the wind resource were better a few kilometers away, the extra energy production might more than justify the added cost of distribution system reinforcements for connection at that location.

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Chapter 4 – Costs

Wind energy markets in Denmark and Germany are large and steady. There is competition and on-going improvements in all phases of the market, including manufacturing, project planning and development, financing, installation, and operations and maintenance (O&M). Both countries have routine procedures for installing and financing wind projects, the latter much like taking out a home mortgage or buying a car in the United States. A thriving export business helps decrease costs for Danish turbines.

There is no inherent reason why costs cannot be reduced in the United States if demand for distributed wind generation grows. Costs for distributed wind generation in a mature U.S. market could approach those in Denmark, which has lower costs than Germany. In fact, the costs of large U.S. wind farms are already similar to those of distributed Danish projects, not including interconnection or grid reinforcement costs. Although the deployment models are different, competition and large volumes have resulted in competitive costs in both nations, as shown in Table 4.1. Germany's somewhat higher project costs, also shown in the table, appear to be due to higher turbine prices and because turbine owners pay interconnection and grid reinforcement costs directly (up to a point) rather than being covered by a system wide fee as in Denmark.

As the U.S. market grows, there will be both opportunities and challenges in reducing the costs of distributed wind generation. These are highlighted in the following comparison of cost drivers for distributed wind generation in the United States and Europe.

Capital Costs. Capital costs are composed of the cost of turbines and towers plus balance of plant costs such as foundations, grid connections, and roads. U.S. costs could be as low or lower than those in Europe once a mature market infrastructure exists.

O&M Costs. The United States has lower labor costs and corporate taxes that may offset higher costs associated with greater distances between distributed wind projects.

Chapter Objectives

Develop a quantitative assessment of distributed wind project cost elements from European and U.S. data, and the sensitivity of those elements to key cost drivers. From that assessment, identify approaches for most effective implementation of distributed projects.

Key Questions Addressed in This Chapter

- What are distributed wind project cost elements in Germany, Denmark, and the United States?
- What differences are observed between the Danish, German, and U.S. markets? What factors are most influential in each market? What implication do costs in Europe have for costs in the United States?
- How do distributed project costs compare with those of larger wind farms?
- How do project cost elements vary for different project scales, number and size of turbines, financing approaches, development schedules, geographic factors, and other infrastructure or market-related factors?
- What are the best approaches to minimizing cost to effectively implement distributed projects?

Wind Resources. Rural areas in the United States have more available sites and better wind resources than Europe does. Better resources translate to higher energy production and better investment returns.

Land Costs. U.S. land costs vary tremendously but are generally lower than land costs in Europe.

Financing Costs. In a mature market, financing costs in the United States might be lower than in Europe because of favorable interest rates.

However, the size of subsidies (if any) and the risks associated with investments in new technology will impact financing costs in the near term.

Approval Processes. Because there is less federal authority over land use planning and permitting, these processes are more expensive and time consuming in the United States than in Europe.

Grid Reinforcements. Grid reinforcements will cost more in the United States than in Europe, which has more robust distribution systems and shorter distribution feeders, on average. Many U.S. distribution lines will require expensive upgrades to interconnect distributed wind generation.

Understanding project costs is critical for evaluating the opportunities for distributed wind generation in the United States. This understanding can also inform policy decisions and the (possible) creation of incentives for distributed wind generation. This chapter presents strategies for lowering the cost of distributed wind generation. It also compares costs for distributed wind projects in

Denmark, Germany, and the United States with costs for bulk wind power generation. Specific distributed wind projects in Germany and the United States are discussed in some detail. For consistency, capital costs are reported on a dollars per kilowatt (\$/kW) basis. The authors converted European currency amounts to U.S. dollars using conversion rates from July 1998.¹

DISTRIBUTED WIND PROJECT COSTS IN EUROPE

Danish turbine costs have declined as their wind industries have gained experience with deployment and as turbine sizes have increased. The capital cost of turbines has decreased from \$1,119/kW (in 1987\$) to \$807/kW (in 1996\$), as shown in Table 4.2. This decline of 28% over 15 years would be significantly larger if costs were adjusted for inflation. The standard deviation for turbine costs in the table is \$41/kW, or about 4%. The small variation reflects the fact that the Danish market has reached a competitive equilibrium and there is not much room for additional cost reductions with volume discounts [Andersen 1998]. Risø National Laboratory in Denmark has found little difference in capital cost between projects using

clusters of up to 10 turbines versus single turbines. Although some Danish manufacturers have higher list prices than others, customers know to compare turbines on a \$/m² basis, which forces manufacturers to compete for actual sales prices. In general, list prices represent an upper limit, with actual sales prices ending up lower [Madsen 1998].

German wind project costs are 25% higher than those in Denmark and the UK [Millborow 1997]. Germany also has an 80% higher feed-in tariff than in the UK. Because lending

Country	Large projects ¹	Small projects ²	Small turbines
United States	950 - 1,050	1,100 - 1,400	1,500 - 3,000
Denmark	no data	950 - 1,050	not researched
Germany	1,150 - 1,250	1,200 - 1,300	not researched

Table 4.1 Capital cost ranges for distributed wind projects (\$/kW) (1998\$).

¹ Costs for the United States represent projects greater than 25 MW; all but one of the German projects had fewer than 13 turbines. U.S. data source is [Electric Power Research Institute 1997]. German data source for large and small projects is combination of [Deutsches Windenergie-Institut 1998] [Kramer 1996] [Durstewitz] [Rehfeldt 1998 and 1997]. Details of costing are contained in technical appendices to this report.

² Costs for the United States are based on experience with new turbines and interviews with several current developers and manufacturers and assume simple interconnection and no grid reinforcement. Total cost can be substantially higher if those costs are incurred. Costs for Denmark are based on 1-10 turbine projects; costs for Germany are based on single turbine projects. Denmark and Germany include all owner interconnection and grid reinforcement costs (but not utility costs). Source for U.S. data for small projects and small turbines is [Gilbert 1999]. Source for Danish data is [Risø 1998] [Kægaard 1998] [Jensen 1998] and [Andersen 1998].

¹ The following conversion rates were used in this chapter: Danish Kroner have been converted to US \$ at the exchange rate of 6.5 DKK = 1 US\$. Deutschmark have been converted to US \$ at the exchange rate of 1.625 DM = 1 US\$. ECU have been converted to US \$ at the exchange rate of 0.8784 ECU = 1 US\$. Pounds have been converted to US \$ at the exchange rate of 0.6126 £ = 1 US\$.

rates and financial structures are equally favorable in all three countries, the higher tariff should provide a comparable return to German investors. However, financial returns to some wind project owners have been reported to be very close to the margin [Knight 1997]. Since turbine prices and feed-in tariffs are relatively constant, returns must vary in Germany as a function of local wind resources. Projects in low-wind inland areas continue to be built. Thus, projects in areas near the coast with better wind resources are



Figure 4.1 Lac Qui Parle School's 225-kW Turbine. In Minnesota, the Lac Qui Parle school district installed a 225-kW Micon wind turbine to save energy and money and to demonstrate good environmental stewardship. Experience with this and other recent projects suggests that there is no reason costs cannot be reduced if the demand for distributed wind generation grows. Photo courtesy of Thomas A. Wind.

		Turbine Size (kW)							
		55	75	95	150	225	300	500	600
Installation year		1984-85	1985	1985	1991			1994-95	1996
Dollar year		1987	1987	1987	1991	1993	1993	1994-95	1996
(\$/kW)	Turbine ex works	1,119	882	988	965	957	877	838	807
	Foundation	112	82.1	81.0	82.1	54.7	46.2	37.8	38.2
	Grid connect	126			151	147	123	88.6	73.8
	Electrical installation	42.0	164	130	41.0	30.8	23.1	4.31	5.13
	Communication				20.5	13.7	10.3	4.31	3.59
	Land				29.7	34.2	30.8	31.7	26.4
	Roads				15.4	13.7	12.8	12.0	10.0
	Consulting services	33.6	20.5	16.2	31.8	27.4	23.1	11.1	9.23
	Finance charges				35.9	19.8	17.4	6.15	5.13
	Insurance							20.9	24.1
	Other	16.8	26.7	16.2					
	Total	1,449	1,175	1,231	1,372	1,298	1,164	1,055	1,002
Avg. prod. (MWh)		116	145	169					

Table 4.2 Variation of Danish wind turbine project cost with turbine size and year.¹

¹ Source: Danish Energy Agency, Risø National Laboratory. The data for installation years 1984 to 1988 are based on 18% of all turbines installed in that period. The data for installation years 1989 to 1995 are estimates based on price lists. The data for 1996 are based on 33 turbines installed in 17 projects. One project has eight turbines, another has seven turbines, another has four turbines, and there are 14 projects with one turbine each. The total number of 600-kW turbines installed in 1996 was 225.

Large Wind Farm Costs: The Holtreim Installation

Europe's largest wind farm, a 52.5-MW installation at Holtreim in north Germany's Ostfreisen area, began producing power in July 1998. Windpark Norderland GmbH, a local firm, owns 29 of the farm's 35 Enercon E-66 wind turbines. Three hundred local families own the remaining six 1.5-MW machines. Each shareholder purchased a minimum of one share in the turbines at \$2,900 per share. Wind farm costs totaled about \$66 million (\$1,257/kW) and were comparable to the cost of smaller distributed generation projects. The Holtreim wind farm produces about 130 million kWh of energy each year.

likely realizing higher returns as a result of the tariffs [Davies 1999].²

The same turbines are more expensive in Germany than they are in Denmark. The Danish wind industry is more mature than the German and has several additional years of manufacturing experience and higher cumulative volumes. However, it is not clear how their production costs compare. All that can be said with certainty is that Danish manufacturers should be operating at a higher profit margin in Germany than in Denmark.

Turbine costs have been declining in Germany for 8 years as project cost effectiveness has increased. According to the Institut für Solare Energieversorgungstechnik (ISET), turbines in the 500-kW to 1-MW range cost between \$900/kW to \$1,000/kW. Between 1990 and 1996, the initial cost per annual kWh, a standard measure of cost-performance, declined from \$0.59/kWh/yr to \$0.33/kWh/yr for turbines with rotor diameters of 32 meters to 45 meters—a cost reduction of 45% over 7 years. A recent German Wind Energy Institute survey indicated that turbines were about 5% more expensive in single projects than in clusters or wind farms [Rehfeldt et al. 1997].

Balance-of-Plant Costs

The German Wind Energy Institute survey discovered that balance-of-plant costs are about 3% less for wind clusters of 4 to 6 turbines than for single turbines [Rehfeldt 1998]. Balance-of-plant costs include resource assessment, project planning, land costs, site development, turbine foundations, and grid connections. Table 4.3 presents typical balance-of-plant costs for 500- to 600-kW wind projects in Germany. Average balance-of-plant expenses are somewhat lower in wind farms because fixed costs can be spread over a larger number of turbines. However, both distributed and wind farm costs vary according to the requirements for new infrastructure and the amount of planning required for project installation. In the past, planning costs for single turbine projects was much lower than for wind farms because owners used to donate their time to their own projects. This is rarely done any more because of the new construction building law, which may also increase land lease costs. Typical land lease costs range from 5% of revenue at a good coastal site to 3% of revenue at an inland site [Rehfeldt 1998]. In certain restricted areas, land lease costs can be much higher.

Both ownership structure and project scale affect planning costs and influence decisions to build a single turbine or a cluster. If a community installs the wind project, planning costs can rise because of the need to obtain consensus on key issues. The institute concluded from its survey that it was not possible to determine whether it is more cost effective to install turbine clusters or single turbines in Germany. Another cost study of 20 wind farms representing 140 MW of capacity agreed with this conclusion [Millborow 1997].

A comparison of balance-of-plant data from Germany and Denmark indicates that grid interconnection costs for 600-kW turbines account for about 30% of the cost difference between Danish and German projects, with turbine prices accounting for the majority of the remainder. This is consistent with the fact that Denmark ratepayers subsidize the entire cost of interconnection on the

² (To calculate the needed tariff, the proper calculation is to multiply, not add, the 43% higher energy and 25% higher cost percentages, i.e., $1.25 \times 1.43 = 1.79$, or rounded = 1.80, or 80% higher). The study claims developers in Britain require real rates of return around 8-9% and German equity partners are likely to require higher rates. However, subsidized loans in Germany tend to offset these different requirements, making financing costs approximately equivalent for the two countries.

high voltage side and grid reinforcement, while German project owners must pay a significant fee for reinforcement. Public data on utility's actual reinforcement costs have not been made available in either country—only the partial costs paid by wind project owners are reported—so a quantitative comparison of real costs is not possible.

Denmark's Risø National Laboratory believes that there are no significant differences in balance-of-plant costs (on a \$/kW basis) due to the number of turbines in a distributed project. Other issues in Danish balance-of-plant costs are highlighted below.

Foundation Costs. Foundation costs in Denmark range from \$38/kW (the average cost in 1996) to about \$130/kW if the site is a wetland.

Resource Assessment Costs. These costs, which are significant in the United States, rarely impact project owners in Denmark. Manufacturers are responsible for wind resource assessments and use a relatively low-cost modeling approach to data gathering. Because of the country's extensive experience with wind, site measurements are no longer necessary.

Grid Connection Costs. To ensure their cooperation, the Danish government allows utilities to add a small surcharge to estimates for grid

reinforcements. Surcharges can be as much as \$15,400 per 600-kW turbine (\$26/kW) [Andersen 1998]. A utility's overall costs are recovered from a national fund subsidized by all ratepayers.

Land Costs. Even though land costs have risen sharply over the past 10 years, land costs on a \$/kW basis remain relatively unchanged. Increases in turbine size, technology cost and performance improvements, and excess margins on subsidies have made up for the difference in land costs. Landowners have benefitted by being able to command higher prices for their land while getting increased output from their turbines. As of mid-1998, a one-time payment for land in Denmark ranged from \$7,700 (\$12.8/kW) in the east to more than \$46,150 (\$77/kW) on the west coast where there is a better wind resource [Madsen 1998].

Operations and Maintenance Costs

O&M costs decrease (as a percent of investment) as turbine size increases, according to a statistical model developed by the Danish Energy Agency and Risø National Laboratory. Not surprisingly, the model also shows that O&M costs increase with the age of the turbine. O&M costs range from 1% of total installed cost per year for relatively new

	Single turbine system		Multiple turbine wind farm	
	Average %	Range %	Average %	Range %
Foundation	7	3 - 14	7	5 - 11
Grid connection ²	17	5 - 29	14	6 - 23
Site development	2	0 - 5	3	0 - 8
Planning ³	4	0 - 12	4	0 - 5
Total average expenses	30		28	

Table 4.3 Balance-of-plant costs for 500-600 kW wind projects in Germany¹ (percent of turbine cost).

¹ Source: Kramer 1996 and Dr. Knud Rehfeldt, Deutsches Windenergie-Institut 1998. Table represents data from 100 projects representing 150 turbines installed in 1996.

² Includes cost for transformer, substation, grid reinforcement.

³ Includes cost for legal fees, reports, and equalization payments.

Distributed Wind Generation Costs in Germany: A Case Study

Peter Ahmels of Lower Saxony is a farmer and president of the German Wind Energy Association. Since 1991 he has owned two Enercon turbines, a 300-kW E-32 and a 500-kW E-40. The turbines are connected to a 20-kV feeder approximately one-half mile away from his farm. His neighbors are far enough away that there have been no objections to turbine noise or appearance. However, neighbors don't want any more turbines in the area, either. Of the 200 local farmers who applied for wind projects between 1991 and 1994, Ahmels was one of only 40 accepted by the local government, which wanted to limit the aesthetic impact of wind generation on the area.

With an annual average wind speed of about 6 meters per second (at 10 meters above ground), the E-32 turbine generates about 700 MWh/yr and the E-40 generates about 1,000 MWh/yr of electricity. The turbines, which cost \$2,154/kW (DM3,500/kW) in 1991, would now sell for between \$923/kW (DM1,500/kW) and \$985/kW (DM1,600/kW). Ahmels had to pay his local utility \$154/kW (DM250/kW) of wind generation capacity for the right to connect his turbines to the grid. This amount was less than it could have been. German utilities have assessed connection costs as high as \$246/kW (DM400/kW). Utilities often take the position that grid reinforcements should include the cost of building infrastructure to handle larger amounts of wind power in the future. Because the timing and amount of added wind capacity is uncertain, it is difficult for wind turbine owners to know if the utility estimates are too high. In Ahmel's case, the utility had plans to build a new 110-kV line. So it justified the charge for his project by including the projected cost of the new line.

Ahmels shared the cost of a new substation with a neighbor, who also purchased two turbines. The substation for all four turbines is near the point of interconnection on the 20-kV feeder. Ahmels' half of the substation and his underground cable cost \$98,500, or \$253/kW (DM160,000, or DM411/kW). Ahmels' paid \$62/m (DM101/m) to install underground cabling. Just two years later, when his neighbor installed similar cabling, the price had fallen to \$28/m (DM45/m).

Ahmels pays about \$3,100/yr (DM5,036/yr) in commercial taxes for his two turbines. These capital and energy taxes are less than 2% of his yearly income from wind generation. About 75% of the commercial taxes remain within the local economy.

Enercon handles turbine maintenance on a contract basis. Enercon's maintenance facility is a half-hour away and it typically takes less than a day to get service personnel to his site. Ahmels' insurance covers both his equipment and lost energy.

Ahmels' primary reason for buying the turbines was financial. He wanted to diversify his income and knew that the Electricity Feed Law was about to be enacted. Buying the turbines was a smart business move because he was also able to take advantage of other state and federal incentives. In addition, wind's environmental benefits meshed well with Ahmels' perception of being a steward of the land.



Figure 4.2 Wind turbine installed on Peter Ahmels' property. Peter Ahmels of Lower Saxony, owner of this Enercon turbine had to pay his local utility for the right to connect it to the grid. Ahmels, who owns two turbines, also shared the cost of a new substation with a neighbor, who owns two additional turbines. Photo courtesy of Thomas A. Wind.

machines to 7% for older turbines approaching their design life of 20 years. However, the model may overstate O&M costs for the long-range forecast years. O&M costs have fallen incrementally over a number of years as manufacturers continued to use proven, low-risk technology. Low O&M costs helped build confidence in wind technology and create long-term markets for distributed wind generation. Newer and larger turbines (500-kW) have lower O&M cost per kWh than their smaller counterparts, but it is still too early to tell how their O&M cost profile will evolve over time because data from large machines are limited. O&M costs for new turbines are very low in the first two years because many owners take advantage of a warranty from the manufacturer for all maintenance, including regularly scheduled visits.

In Germany, O&M costs for turbines 5 years old and older range from 3 - 16% of capital cost per year and 2 - 8% per year for newer turbines, according to a cost analysis performed by Germanischer Lloyd, a German certification firm. O&M costs for older turbines are higher because the turbines tend to be smaller. New turbines often come with a 2-year guarantee, and some German manufacturers in Germany even offer a combined maintenance and repair package. This package eliminates the need for insurance to cover broken parts and loss of revenue.

O&M contract prices in Germany are typically not dependent on a project's size or location. Contract prices are negotiated per turbine. However, single turbine projects have never had the negotiating leverage that today's professional developer with a large project can bring to bear on the contract approval process [Rehfeldt 1998]. Today's O&M costs are more dependent on the existence of infrastructure than on project scale. Costs are spread out over an entire manufacturer's or maintenance company's fleet. Each company competes for its maintenance contracts on the basis of market price.

STRATEGIES FOR REDUCING PROJECT COSTS IN THE UNITED STATES

One key to opening up markets for distributed wind generation in the United States is minimizing costs. In analyzing opportunities for cost reduction, the most obvious place to begin is with existing distributed wind installations. However, this approach is problematic for utility-scale wind

turbines (>20 kW) because almost all of them are installed in large wind farms. These turbines are connected to dedicated collection circuits feeding substations attached to the high voltage grid. It is difficult to draw conclusions about costs from the perhaps couple dozen distributed wind projects that use turbines larger than 20 kW. Utilities own only a few of them. The projects are scattered across the country from Alaska to Iowa, and each one is unique. Although Iowa has 17 distributed wind projects, most other states have only one or two. The absence of a generator cap for net metering in Iowa contributed to the higher level of activity. Many projects came about because an individual or organization wanted to have a turbine for a reasons other than economic profit, i.e., they did not want to lose money, but their motivation was not profit, per se. Many were driven by altruism or environmental concerns. Most projects owe their existence to the sheer determination of one or two key people. Nearly all were turnkey projects by a developer. In the Midwest, developers often bid very low prices just to establish a market presence, and their prices did not reflect typical development and overhead costs. For example, owner overhead costs often were not assessed even though owners spent countless hours planning and evaluating their projects. Many projects enhanced their financial outlook with gifts, grants, or low-interest loans. Others used refurbished turbines. If they existed, requirements for environmental impact assessments and permits were few and far between. Interconnection facilities were simple and low cost. State policies in Minnesota and Iowa (described in Chapter 2) also played a critical role in establishing acceptable financial returns.

Even with the price breaks described above, distributed wind generation was more expensive than wholesale power. Without them, it would be even more so. With the relatively low electric rates in Iowa, for example, it is difficult for wind generation projects to achieve any kind of near-term payback. Thus far, only four projects have been able to obtain long-term sales contracts for \$0.06/kWh with a utility.

There are at the least hundreds of grid connected small wind turbines, 10-kW or less, scattered across the United States. These turbines are connected to homes and small businesses on the customer side of the meter [Bergey 1996]. A 1998 study, which characterized the cost, performance,

and developmental status of wind turbines ≤ 100 -kW in the United States found that equipment costs (turbine, tower, and inverter) varied from \$1,200/kW to \$2,640/kW [Gilbert, 1998]. Generally, the capital costs per square meter of rotor area ($\$/m^2$) and cost-performance (turbine system cost per net annual kWh) decrease as the size of small turbines increases.

An analysis by the authors of this report suggests that power purchase rates would have to be at least \$0.065/kWh—higher than any current utility avoided cost³—to yield an acceptable payback (to project equity) to private investors under specific conditions. The conditions are believed to be typical of what a current farmer-owned project using large turbines in a favorable resource area would experience. The authors examined the impact of various incentives on the payback period, assuming a reference case power purchase rate of \$0.065/kWh. They found that a production tax credit of \$0.015/kWh or a subsidy to lower the capital cost to \$900/kW could lower the payback period to an acceptable range (between 5 and 10 years) in sites down to 13 mph average annual wind speeds, measured at 10 meters above the ground. This result depended on the owner's tax bracket and whether the wind project was classified as business or personal property. Other incentives, including property tax exemptions and low interest loans (1.5% below market rates) had significantly lower impacts. Payback periods at all wind speeds were extremely sensitive to O&M costs. A difference of \$0.01/kWh in O&M cost increased payback periods 7 to 10 years for all wind regimes. Readers of this report are cautioned that an incentive or cost reduction strategy that works well for one project may have a much different impact on another project with different ownership, financial, or wind resource characteristics.

It is interesting to observe that very limited market activity has occurred in Midwestern states with net metering regulations or laws requiring payment for excess at retail rate (e.g. Iowa, Minnesota, Wisconsin), even though the payment level has been around \$0.06-0.07/kWh

A Cost Comparison: Traverse City, Michigan and Algona, Iowa

A comparison of distributed wind project costs in Traverse City, Michigan, and Algona, Iowa, demonstrates the site-specific nature of these costs in the United States. Traverse City Light and Power owns one 600-kW turbine. The turbine is connected to a 13.8 kV distribution line just outside of town. The municipal utility brought the turbine on line in May 1996 for a total project cost of \$650,000 (\$1,083/kW). The utility kept its costs down by using a \$50,000 grant and installing the turbine close enough to town to avoid transmission charges. The utility receives a production incentive of \$0.015/kWh and charges customers a \$0.0158/kWh premium for the wind power. With the incentive and the premium price, the cost of wind power is comparable to other wholesale power purchased by the utility.

Seven Iowa municipal utilities own the 2.25-MW Iowa Distributed Wind Generation Project located near Algona, Iowa. The project came on line in October 1998. It consists of three 750-kW wind turbines located 6.5 miles from a substation on a 13.8-kV feeder. Project costs totaled \$2.85 million (\$1,267/kW). The figure is somewhat high because of extra overhead costs associated with a research study. Researchers are testing the ability of advanced turbine technology to minimize power quality problems on a weak distribution system. Without the costs associated with the research study, project costs would have been \$1,150/kW. The Turbine Verification Program, sponsored by the Electric Power Research Institute and the U.S. Department of Energy, provided \$1.25 million – more than 40% – of the capital cost.

The Iowa project is the first U.S. distributed generation project to include significant system reinforcement. The utilities replaced some reclosers and 5.5 miles of single- and two-phase distribution lines with a three-phase line. The utilities also considered replacing the 1/0 conductor on the 13.8-kV overhead line with a larger 4/0 conductor, but decided to save money and live with higher line losses and more voltage drop. If the wind turbines had not been owned by utilities, they might have required the turbine owners to replace the conductor. Reinforcement costs totaled about \$75,000 (\$33/kW).

³ Avoided costs usually equal the lowest cost of electricity a utility purchases or generates.

and other incentives have been available. Other programs such as the \$0.015/kWh payment for projects under 2 MW and the “Prairie Island” capacity mandate in Minnesota have also played important roles in spurring what market activity has occurred.

The question then becomes: How can potential owners of distributed wind generation bring down costs and improve distributed wind generation’s attractiveness as an investment? There is no one easy answer. As discussed in Chapter 2, government policies and incentives as well as changes in infrastructure would make a significant difference. Desirable infrastructure developments would provide individuals and organizations information and expertise in resource assessment, project development, wind technology, bulk purchases, financing, operations, and maintenance. Without them, capital and O&M costs for most distributed projects are likely to remain well above those for large wind farms. The U.S. experience with turbine manufacturing and bulk wind power generation will likely speed up the development of this infrastructure in certain areas. If the deployment of distributed wind generation increases, economies of scale will reduce costs for project development, installation, operations, and maintenance—although probably not as much as for large wind farms.

Owners and developers could also consider the following strategies to make distributed wind generation a better investment in the early market entry period.

Larger Turbines. European and U.S. data show capital and O&M cost advantages from larger turbines. Some O&M costs are incurred on a per-turbine basis, and large turbines produce more annual kWh. Small turbines that qualify for net metering or whose output can be used on site are the exception to this rule. By pooling resources, cooperatives can afford to buy larger turbines.

Standards and Evaluation Procedures. In conjunction with the development of interconnection standards, the development of simplified evaluation procedures, but not any single or required approach, could reduce the costs for evaluation of interconnection requirements and impacts. Developers may be able to assist in the development of such procedures.

Concentrate Early Development in a Few Geographic Areas. Regardless of whether a manufacturer or service organization performs turbine maintenance, having O&M capabilities close at hand is critical to minimizing costs and maximizing customer satisfaction. Concentrating distributed wind development in one region would not only help keep O&M costs down, but would also allow potential owners in an area to share in costly wind resource assessments. Concentrating distributed development in high resource areas can also have large favorable impacts on project economics, even more than in Germany and Denmark, because of the greater range of resource levels in the United States. However, the extensive U.S. land area may make it difficult to keep early market installations in a limited geographic area.

Aggregated Purchases. Substantial savings are possible if a rural electric cooperative, government agency, or private developer buys a large number of turbines and then sells them to individuals, perhaps with financial incentives attached.

Clusters Versus Single Turbines. Several U.S. developers said they could lower costs by deploying multi-turbine clusters as compared to single turbines. However, there are no field data in the United States to confirm this assertion, and the European experience is inconclusive. German data suggest that small cost reductions, between 5% and 10%, exist for at least some turbine clusters, but the savings are usually offset by higher development costs. Danish data show no cost advantage between a single turbine and a cluster of up to 10 turbines.

Existing Infrastructure. Costs for new wind projects can be minimized by selecting sites with existing infrastructure such as access roads, grid connections, or substations.

Ownership. The cost of developing distributed wind generation can be influenced by who develops and owns the project. For example, private owners could have lower development costs than a corporate power producer because private owners can sometimes use “sweat equity.” There are numerous sites available in the United States for private wind projects.

The cost impacts of ownership by public and private utilities are difficult to predict because of market restructuring. Currently, public utilities using general obligation debt can develop wind projects at lower cost because they utilize tax-free, low-cost debt financing.

One impediment to the widespread adoption of distributed wind generation may be the cost of development as opposed to hardware costs. An independent power producer would likely charge \$100,000 to \$150,000 per project to install a single turbine or small cluster, according to experienced wind developers. The developer's costs would include site selection, land acquisition, legal fees, engineering and cost estimation, permitting, power purchase agreement(s), and overhead expenses. Financing costs, legal fees, bond underwriting, and management fees could top \$50,000 per project. In addition, investors would typically look for a high rate of return (16% to 18%) on small projects. Because they are also likely to want to use the tax credits and accelerated depreciation, the project's debt to equity ratio might be constrained to about 1.4. Interest rates would depend upon the market, but 8% is a reasonable guess. Because of such high fixed costs, an independent power producer could not economically develop one or two turbine projects in an open competitive market.

The situation is different if the project owner is a local farmer, school, business, or utility. Financing costs can be minimized, particularly if a local line of credit or cash is used. If the owner already owns the land (as is commonly the case), leasing costs or royalties would be eliminated. Permitting should also be easier for the owner because he would be dealing personally with local officials, who are likely to be acquaintances, if not friends. If the owner plans to use wind energy to offset his own energy purchases, he can negotiate a standard tariff or agreement with the local utility. Finally, if an owner has expertise or experience in construction management, he may be able to manage the project without outside engineering, procurement and construction services. Taken together, these factors could reduce the development costs by 20% to 50%.

Economies of scale in project development, installation, operations, and maintenance are possible in the United States if there is sufficient interest in distributed wind generation to result in significantly more projects. However, the large

U.S. land area will make it more difficult here than in Europe to build the necessary infrastructure to support distributed generation. Current practices for resource assessment, financing, project development, O&M, and bulk power generation have been developed for large wind projects. It will take time to develop an infrastructure and knowledge base better suited to distributed generation. There is no inherent reason why costs cannot be reduced as demand for distributed wind generation grows. Until this occurs, however, capital and O&M costs for most distributed projects will remain well above those for large wind farms.

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The NWCC was formed in 1994 as a collaborative endeavor composed of representatives from diverse sectors including electric utilities and their support organizations, state utility commissions, state legislatures, environmental organizations, wind equipment suppliers and developers, green power marketers, consumer advocates, agriculture and economic development organizations, and local, regional, state, tribal and federal agencies. The NWCC identifies issues that affect the use of wind power, establishes dialogue among key stakeholders, and catalyzes activities to support the development of an environmentally, economically and politically sustainable commercial market for wind energy.

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