Obstacles to the Widespread Use of Grid-Connected Small Wind Energy Conversion Systems (SWECS): Zoning, Installation, Maintenance and Other Issues of Implementation.

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Executive Summary

Small wind energy conversion systems (SWECS) are being left out of the tremendous growth that is currently sweeping the wind industry. Wind power is by any measure the fastest growing segment of the world electricity industry. This growth is contrasted by the relatively stagnant application of small-scale wind machines. In order for SWECS to play a serious role in the generation of electricity, romantic ideas of self-sufficiency must be set aside, and the real obstacles to implementation faced head-on. SWECS installed by homeowners, farmers, and small businesses, have the potential to contribute to the electrical power grid -- increasing its capacity, decreasing the load on the grid, and increasing grid stability. Further, SWECS force the consumer of electricity to take the role of producer, a cultural shift that has the potential to encourage more efficient lifestyles. SWECS are well positioned to play a role in the movement towards zero-net emissions buildings. SWECS can offer an important source of income to those living on fixed (the elderly), variable (farmers), or declining incomes. Despite these attractive qualities, there are real barriers to widespread use of SWECS. However mundane, these obstacles prevent the large-scale implementation of small-scale turbines. Primary among these are local zoning approval, effective planning and installation, and issues related to maintenance and reliability. This paper aims to look past the benefits of SWECS that proponents spend so much time lauding and address the obstacles to wide-scale implementation. It is found that maintenance and reliability are among the most significant challenges that SWECS face. Other issues of concern are local zoning issues and issues of safety. Widespread acceptance of SWECS will not succeed until these issues are delt with satisfactorily.

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1. Introduction and Background

At a point in history where a renaissance of wind-derived power seems immanent, the future of small wind power is uncertain. Widespread use of small wind energy conversion systems (SWECS) will only happen if romantic ideas of self-sufficiency are put aside, and the mundane issues of SWECS implementation are met head-on. SWECS share with their larger cousins the general properties that make wind power so attractive: environmentally benign, producing no pollutants, they provide a reliable source of energy, and the "fuel" is for all practical purposes inexhaustible. They also offer attractive qualities of their own. SWECS are compatible with the movements towards distributed power generation and building-integrated power generation. By their nature they are very scalable. SWECS may be appropriately applied to a wide range of climates and landscapes allowing for greater flexibility in siting. And perhaps the most attractive aspect of SWECS is that they allow the end user of the energy to become the producer. This enforces accountability for energy use, and encourages awareness of energy use and greater energy efficiency. The implementation of SWECS is met with a number of obstacles, including zoning regulations, installation challenges, safety issues, maintenance issues, and difficult relationships with utility companies. These barriers must be addressed before any large-scale use of SWECS is feasible.

1.1. Current Trends in the Wind Industry

Current power industry trends, especially in Europe, suggest that by any measure wind will remain the fastest growing electrical generation technology in the coming decade (Moore, 1999). Due to a combination of issues related to the structure of power delivery and economic factors, the next generation of wind power will likely come from wind farms of very large (MW plus) wind turbines. This future strikes a sharp contrast to the historical use of wind conversion technologies. Historically the generation of wind-derived power typically took place on a small scale, local to the end use. Wind-derived power can be found at the heart of the development of sophisticated irrigation, trading, exploration, and military development. Today the early applications of wind, for irrigation and ship power, have been marginalized by the apparent abundance of cheap power derived from fossil fuels.

The 19th century saw widespread use of SWECS in the United States of America and abroad. At their peak use in the early part of the 20th century there were as many as 6 million installed wind machines (Peters et. Al. Chapter 15: Wind Energy. Draft copy of Sustainable Energy.). As the role of electricity became increasingly important to developed countries, wind machines gave way to other methods of power generation. Following a period of excitement in the mid to late 1970s accentuated by the 1978 National Energy Act, large-scale wind farms for electricity generation appeared in the 1980s (Gipe, 1995). These wind farms, typified by Alamont Pass, use 55-360 kW wind turbines (www.nrel.gov). The past couple of years have seen the beginning of a series of very large wind turbines built in Europe. These turbines can be as large as 3 MW in capacity, and are beginning to be built off-shore (www.windpower.dk).

1.1.1. Large Wind Turbines

Despite technological successes such as the Tvind 2 MW machine (a very large wind machine built in the early 1980s: see www.windpower.org) very large wind turbines were deemed uneconomic as recently as 1991 (Hensing. 1991). However, recent wind farm projects such as Denmark's Middelgrunden (www.meddelgrunden.dk), are paving the way for a future of very large offshore wind farms. These wind farms address a number of the traditional obstacles to wind development. Built offshore, they avoid the problems of siting and local acceptance that stymie many wind projects. Wind quality is consistent and generally very good (Barltrop, 1993). And land use, a major issue in well-developed parts of the world such as Europe, is no longer an issue. The economics have brought the price of electricity supplied by these wind machines within competition of traditional (fossil) electricity generation.

1.1.2. Niche Market Small Wind Turbines

The development of small wind turbine technologies have been largely left behind in recent years as governments and large companies have focused their research and development efforts are large wind machines. As large turbines have reached an impressive level of sophistication, the general technology for small wind turbines has remained stagnant. The small number of small turbines approved to the IEC standard reflects this state (Clausen and Wood. 1999).

Despite current trends, the number of small turbines far exceeds that of larger turbines. Currently the major application of small wind machines is in various niche applications. Though it is difficult to obtain current statistics, in the past it has been estimated that nearly 100,000 of these small turbines are manufactured and sold annually (Twidell. 1987). Current use of these turbines include grid-connected power generation for homes and businesses, off-grid power for homes and businesses, water pumping, service to remote locations, power for boats, and power for remote sensing devices (Gipe, 1993). Of these uses, only the first two, electricity generation for home and business, can be compared directly to wind farms. These applications are the only type of SWECS that have the potential to displace fossil fuels. Grid-connected power is particularly attractive because it has the potential to eliminate the need to battery storage, making the entire system more reliable, and less expensive (Heier. 1998).

1.2. Future of Wind

Based on current trends, it is likely that the role of very large wind machines in the generation of power is going to become very important in the coming years. The role SWECS in future power generation is less clear. There is a good deal of research that needs to be carried out. Beyond technological development, there are more fundamental issues that stand in the way of widespread use of SWECS. Currently it is a hardy few that are willing to deal with the zoning approval battles, the technical process of installation, maintenance of the towers, and general safety issues associated with wind machines. Because of a perceived battle against fossil fuels, proponents of wind tend to trumpet the achievements of wind power technologies and write-off challenges, citing technological advances that will soon be made. If wind power is to be adopted on a broad scale, especially if this wind power is to be produced from SWECS, issues of implementation must be addressed seriously.

1.3. Small Wind Energy Conversion Systems

1.3.1. Benefits of Widespread use of SWECS

Small wind energy conversion systems have a number of qualities that make them an attractive addition to an electricity generation portfolio. For one, they are a renewable energy source that can be economic on small scale. Furthermore they operate with zero emissions. This puts SWECS in the exclusive company of photovoltaics and hydropower. SWECS have the potential to play a crucial role in developing zero net emissions buildings, a role they have already taken in thousands of homes and small farms around the world. SWECS technology is in a position to benefit greatly from the advantages provided by serial installation. The gradual introduction of many SWECS would lead to advances in technology that would greatly benefit later SWECS.

Despite the aforementioned limitations, SWECS offer far greater siting flexibility than large wind farms (Anonymous. 2000). Small wind machines can be placed in farmers fields without the extensive planning, construction periods, and capital investment that wind farms would require. Decentralized power generation is inherently flexible, allowing for the utilization of small patches of useful land that could not support a full wind farm. For these reasons SWECS are very attractive from the perspective of land management.

Another attractive quality of small wind power is that it allows for the merger of the producer and consumer of electricity. Much of the inefficiencies of home power use can be traced to two things. One, the cost of power is negligible for many people in developed countries, especially in the United States. Therefore leaving a couple of incandescent lights on in an empty room of a typical house does not have any serious impact on the occupant’s budget. Second, there is no accountability for wasteful behavior. Consumers of electricity assume that there will always be an adequate supply of power. They are not directly impacted by capacity that must be added to a grid, even if the necessity of that added capacity could be avoided by simple conservation measures. Consumers are insulated from most small and large fluctuations in the cost of electricity, and from the results of using fossil fuels to maintain inexpensive power. A farmer with a grid-connected SWECS could encourage her family to conserve power, and may even take measures to install energy-efficient appliances and lights if she could expect to earn an income from excess power she could sell to the local utility.

SWECS are very attractive in the face of volatile energy prices. For this reason they may be an appropriate consideration for people who live on a fixed or unstable income, such as the elderly, farmers, and inhabitants of rural areas. Though an economic analysis of wind technology may not be a driving force towards this type of power generation, the potential of "free" electricity after the initial investment is paid off (typically 4-9 years), or even a supplemental income in the case of overcapacity, may be very attractive to those planning retirement (Gipe. 1993).

1.3.2. Obstacles to Widespread use of SWECS

Balancing the great benefits of SWECS just mentioned are an equal number of concerns, obstacles, and barriers to the wide-spread use of SWECS. Atop the list is the fact that SWECS have not been successfully incorporated into urban settings. There are obstacles to such implementation, and few have attempted to address those obstacles. There are several recorded cases of SWECS on the roofs of apartment buildings (Putnam. 1974), but for reasons that will be detailed shortly, this is not an ideal siting situation (Marier. 1981. and Park. 1978). This, combined with the fact that more than two thirds of the world's population live in urban areas, may lead to pessimism about widespread use of SWECS for electricity generation (U.S. Bureau of the Census. 1999).

Another obstacle to development of SWECS is convenience. The current state of small wind machine technology requires a certain amount of maintenance. In a society that has seen lifestyles grow increasingly busy, it is not likely that homeowners will opt for a power option that will require any of their valuable time. Therefore maintenance and reliability are key issues that must be taken seriously, however mundane they may appear.

Another concern about SWECS implementation is safety. Public safety (trespassers climbing the wind towers) and the owner's safety must be carefully considered if SWECS are to gain widespread use. This is especially important due the public's innate suspicion of emerging technologies. A couple of accidents involving wind towers could lead to negative publicity that could rapidly quench any forward development.

Economic barriers include economies of scale. By this consideration alone there is no advantage to small wind machines over large wind machines. The nature of SWECS call for greater system complexity than is found in wind farms. Rather than 50 large (500 kW) turbines on a compact wind farm, one would need to install 25,000 small (1kW) turbines spread throughout a rather large area. Each of these machines would need the attention of some individual through the process of planning, installing, and maintaining. Simply considering the obstacle of local zoning boards, the case of one wind farm might involve one lengthy process while the installation of 25,000 small machines might involve 25,000 separate zoning procedures.

2. Technical Differences Between Large and Small Wind Turbines

2.1. Fundamentals of Modern Wind Turbines

All wind turbines, large and small, can be described by the same fundamental physics. The objective of any wind machine is to convert the kinetic energy of the wind to energy useful for human use. Most basicically, wind machines can be divided into two categories, horizontal axis and vertical axis. Figure 1 shows the difference between typical vertical and horizontal wind machines noting the positions of the blades, axis, and generators for each. Most wind machines today are horizontal axis machines with 3 blades (though 2 and even 1-bladed machines have been built). The lift a blade generates can be crudely described as similar to that of an airplane wing. The blades of most wind turbines in operation today were modeled after airplane wings. Recently projects have been undertaken to redesign the blade and such redesigns have led to 25-30% increases in performance (www.nrel.gov).

Figure 2 depicts the flow of wind past a wind turbine. In lieu of turbulence caused by obstacles, airflow is laminar at the height of a wind turbine. This laminar air is disturbed by the windmill, and slows down as the kinetic energy is transferred to the spinning blades. The result is a region of turbulent low speed air downstream of the wind machine.

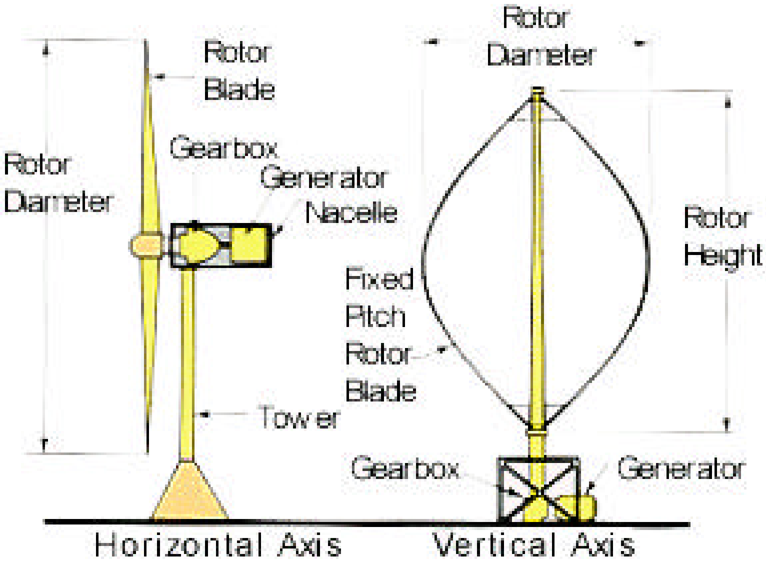

Figure 1: Comparison of Horizontal and Vertical Axis Wind Machines. (www.awea.org)

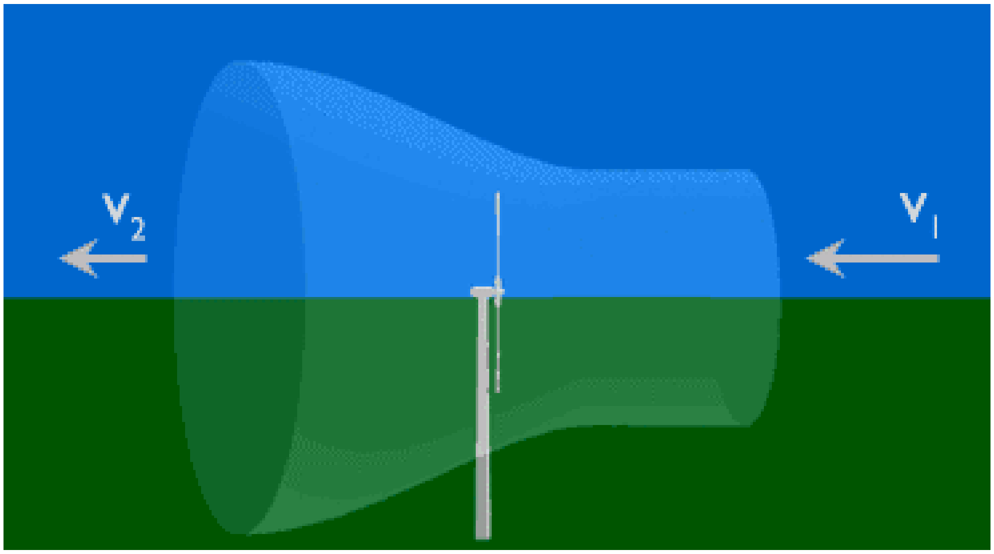

Figure 2: A Wind Turbine Deflecting the Wind. (www.windpower.org)

2.2. Technical Characteristics of Small Turbines

Typically small turbines are defined by their power-generating capacity, and rather arbitrarily considered as turbines under 100 kW in size. Large turbines are generally between 300 kW and 3 MW. An alternate definition relies on two characteristics that are common to nearly all small wind turbines. Typically small wind turbines depend on aerodynamic torque for starting and use a tail fin to point the blades into the wind (Clausen. 2000).

The relationship of various properties important to wind machines are shown as they relate to the blade radius in Table 1. The minimum height of a wind machine's tower is directly proportional to the radius of the rotor. Other important relationships to note from Table 1 are the relationship of starting torque, power output, and noise output. These relationships have important effects on wind turbine design (Clausen. 1999).

Parameter	Dependence
Reynolds Number (*Re*)	R
Minimum Tower height	R
Power Output	R^2
Noise Output	R^2
Centrifugal Loads	R^2
Starting Torque	R^3
Inertia of Blades	R^5

Table 1: The Dependence of Important Parameters on Blade Radius.

Since tip speed is crucial to power generation, small wind turbines must spin faster than their larger counterparts. This fact strongly contributes to the relationship between noise output and size. Since these turbines rely on aerodynamic torque for starting, and because Reynolds numbers (*Re*) are typically small, their operational efficiency is strongly dependent on performance at low wind speeds. Recent advances in the development of small turbines address this issue (Clausen, 2000).

3. Land Use/Zoning

3.1. Siting

There are two primary considerations that must be taken into account for proper siting of a wind turbine. The first is geographical location. The second is location within a given site. These two considerations are distinguished by their scope (the first is a macro-property, the second a micro-property) and the manner by which they are assessed.

The quality of a wind resource depends on four things, the speed of the wind, the quality of the wind flow (laminar or turbulent), the direction of the wind, and the consistency or reliability of the wind. Clearly when measuring the wind flow in a given location there will be fluctuations. One might be led to think that it is merely the average wind speed that is of importance. However, this is not quite the case. Many wind turbines, especially small wind turbines, rely on the wind to start turning. Therefore there is a minimum speed below which they will not begin to spin. If the average wind speed is high, yet erratic meaning that there are frequent cases where the wind speed is below the stall speed of the turbine, the resource is not very useful. Laminar wind is important to efficient operation, which is part of the reason for elevating the wind turbine. Though not entirely precise, wind charts can assist in the process of planning for the placement of a wind machine. Charts of the continental United States and the Northeastern United States wind resources are included in Appendix A along with an excellent wind resource map for Denmark. Wind potential is measured in a system of classes as described in Appendix A. Anemometers can be used to gather precise data about wind speeds in a local area, but the costs of collecting a years worth of data is prohibitive for SWECS ($500-$1500: www.doe.gov).

The speed of wind reaches a maximum at the crest of a ridge. This is a flow effect that can be understood by a simplified description. The air moving close to the ground tries to keep speed with the wind above it because laminar flow (which results if the layers are moving at the same speed) is energetically preferred to turbulent flow (which results from the layers flowing at separate speeds. Thus, as the wind approaches a hill, the wind closest to the ground has more ground to cover to move the same horizontal distance as the wind that is above the crest. This wind speeds up to match the wind above it resulting in higher wind speeds (Pacific Northwest Laboratory. 1980). Other effects such as the “tunnel effect” may be important in mountainous regions.

Ground obstacles (such as a building, or tree) can be disrupt wind flow. Thus, in addition to reviewing the wind resource charts and the geography for a given area, it is important to take into account the local disturbances to wind flow and place the wind turbine accordingly. Wind of high quality will typically come from a very consistent direction. However winds shift, and the frequency and magnitude of these shifts must be taken into account in the planning and design stages.

Proper siting is one of the most complex issues of wind turbine installation. Analysis comparing the siting efficiency of small and large wind turbines has not been carried out. It is known that small wind turbines are far more flexible and involve far less planning than large turbines if compared unit to unit (Pacific Northwest Laboratory. 1980). Clearly small turbines can be tucked into sites that would not be considered for a farm of large turbines. Furthermore, small turbines, closer in scale to common objects on the landscape, may be more likely to find acceptance from neighbors (Figure 3). On the other hand small turbines tend to be set up on shorter towers and thus do not benefit from the high quality winds that move at higher altitudes. Clearly small turbines offer more flexibility in siting and can take advantage of sites that could not be utilized by large turbines.

Weighing against the consideration of flexibility of site location is the issue of footprint. For geometric reasons large windmills have a smaller footprint per unit of power produced as shown in Figure 4 (rotor diameter is proportional to tower size, swept area is proportional to power).

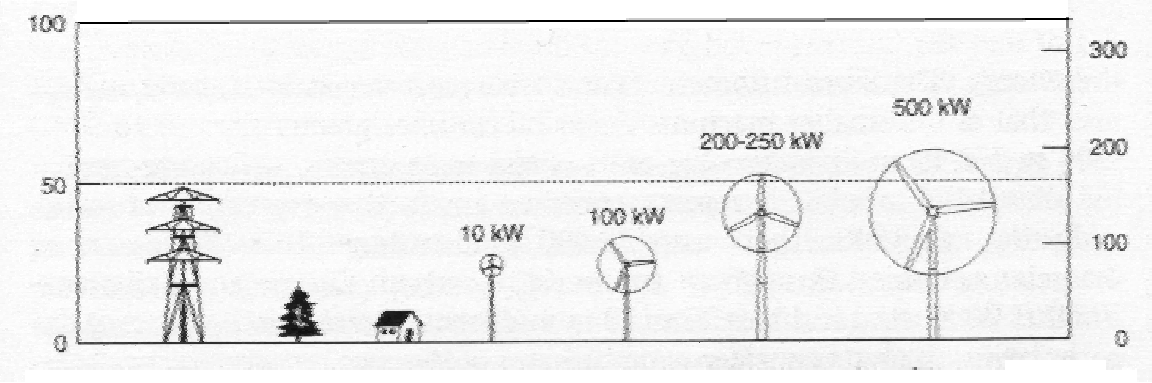

Figure 3: Comparison of Various Sized Turbine to Common Landscape Items (Gipe. 1995).

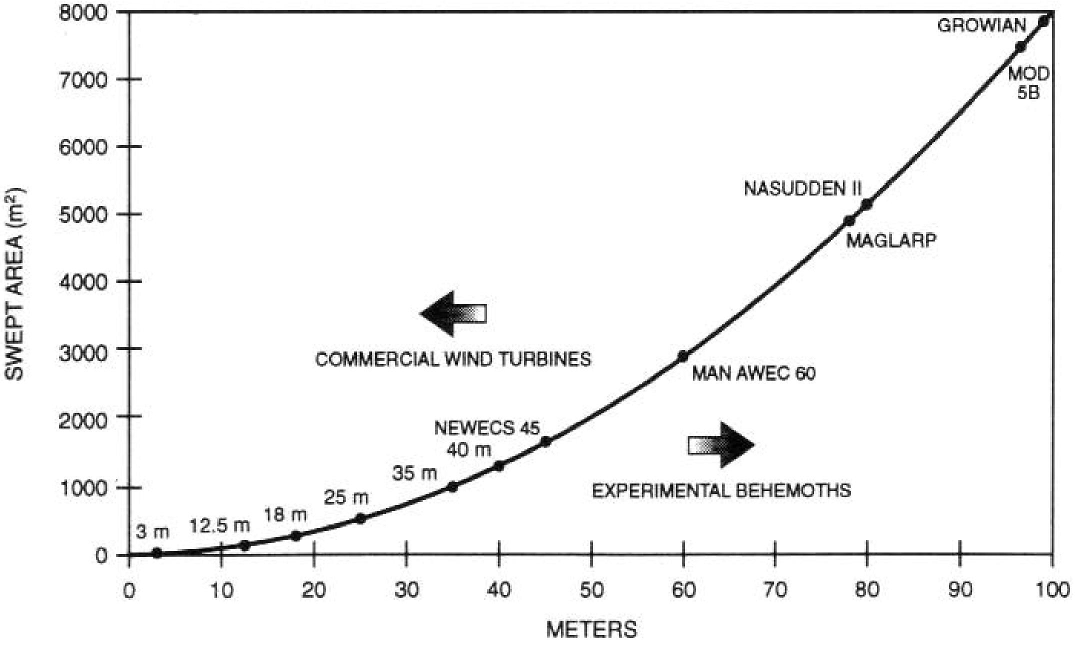

Figure 4: Area Swept vs. Rotor Diameter (Gipe. 1995)

3.2. Local Approval

The importance of zoning issues to the implementation of SWECS cannot be overstated. If successful, the process of zoning approval for wind machines is typically a long and arduous process (Gipe, 1993). This is in stark contrast to the relatively streamlined process of installing similar structures such as cellular communications towers*. Despite its importance, very little work has directly addressed this issue. This may be related to the fact that the issue is highly variable from one community to another and depends on local climates and acceptance. Issues regarding zoning approval fall into several categories (1) aesthetic objections, (2) safety and building codes, and (3) wind rights.

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* The landmark Telecommunications Act of 1996 essentially forbade local governments from standing in the way of cellular communications tower development. This has been a controversial issue especially in picturesque rural towns that do not want the towers in their area. Section 704(a) of the Act states: "The regulation of the placement, construction, and modification of personal wireless service facilities by any State or local government or instrumentality thereof shall not unreasonably discriminate among providers of functionally equivalent services and shall not prohibit *or have the effect of prohibiting the provision of personal wireless services*."
In an interesting side development, companies have sprung up that specialize in disguising towers. Including one company that builds branches around the towers disguising them as trees (albeit very tall ones). The author suspects that there is a lot of learning from this process that could be applied to SWECS.

Many local regulations forbid building structures greater than 35 ft in height. Small wind towers tend be between 40 and 80 ft in height, some are greater than 100 ft. Therefore such local requirements essentially ban the building of wind towers (Lawless-Butterfield. 1981). One tact that individuals wishing to build towers have taken is to request that wind towers be considered a member of a class of structures (church spires, belfries, cupolas, domes not used for human occupancy, chimneys, water tanks, and silos) that are exempt from this size limitation.

Wind rights, while not currently an important issue, would quickly come to the forefront of obstacles to SWECS if the technology every found widespread use. Neither state, federal, nor local laws clearly define the rights to the wind (Lawless-Butterfield. 1981). Consider the following conflict. Individual A's land abuts that of individual B. A has an existing wind machine. However B's property is upwind of A's wind machine. If B decided to build a wind machine, the quality of A's wind will be severely degraded. If SWECS are to become widespread, new laws and precedent would need to be set to deal with this type of situation.

4. The Grid

4.1. PURPA

In 1978 the United States Congress passed a landmark act aimed at stimulating the use of small-scale alternative energies. The act, titled the Public Utility Regulatory Act of 1978 (PURPA), imposed two requirements upon public utilities that are to the benefit of small power producers. (1) Utilities are not allowed to discriminate against those who use very little or intermittent power, and (2) utilities are required to purchase, at a reasonable price, excess power produced by their customers. This essentially opened the grid to SWECS.

4.2. Benefits of Grid-Connectivity

There are a number of benefits to SWECS of grid connectivity. (1) It allows a customer to use conventionally produced electricity in times of low of very high winds. This eliminates the need for battery storage. (2) It allows the customer to sell excess power to utility companies. This helps make SWECS more economically attractive. A grid-connected system can become a supplemental source of income. Furthermore, as will be discussed later, the power from SWECS is typically sold to the electric company at prices closer to the consumer cost than the bursar. This helps compensate for the disadvantage SWECS have due to economies of scale. (3) Grid-connectivity allows for greater flexibility of wind turbine siting. For instance, a farm houses are often located at the base of rolling hilly land. Furthermore it is not uncommon for a utility line to blaze across a farmers property crossing a ridge. The ridge provides a far superior site for a wind turbine than the low land where the farm house is situated. In this case a farmer could connect the wind turbine to the power lines, sell high-grade power to the utility, and draw power for her house from typical street power lines (Gipe, 1993).

4.3. Connecting Wind Power to the Grid

The process of connecting to the grid poses a challenge to the common homeowner. It is very important that a trained electrician carry out the process. There is an acute danger of immediate electric shock or fire hazard that could be caused by improper wiring. Furthermore, due to the siting considerations of wind turbines, it is not uncommon that the best site is far from a utility line. In this case lines must be built to the wind machine. The techniques common to construction of utility lines can be applied without any serious modification to the case of wind power. Experience with large remote wind farms suggest that this is not a serious obstacle if treated with care (Davenport. 1991).

4.4. Relations with Power Companies

PURPA has not provided an entirely win-win situation. The benefit to SWECS and operators of other power generation alternatives comes at some cost to utility companies. And while it is important to utility companies to comply with the laws, they are not necessarily eager about the process. In all fairness, PURPA does have advantages to utility companies. Distributed power can lead to a more stable system (Ubeda. 1999). Consumers who are supplied by alternatives such as wind power may not be affected by brownouts and blackouts. Furthermore costly increases in capacity (that lead to temporary over capacity) can be avoided or postponed if a utility leverages inputs to its grid from sources such as SWECS. On the other hand a weak grid can have a strong impact on the effectiveness of wind generation. This is particularly important in developing countries where grids are not as mature as those found in developed countries (Rajsekhar. 1998).

5. Installation

5.1. Approaches

Typically SWECS machines are purchased by a company or individual from a commercial manufacturer. A list of current manufacturers is included in Appendix B. SWECS towers fall into two categories: (1) mono-posts and (2) truss-style structures. Depending on the design of the structure the tower may or may not utilize tension lines and anchors. The process of installation is fairly basic. Typically the ground of the site is leveled if necessary. A foundation of concrete is poured (this helps distribute the weight of the base of the tower leading to improved stability). Anchors are laid if necessary. The tower is erected either by crane or pulley system. Towers typically have some type of ladder which allows a person to climb the tower. Finally the wind turbine is assembled on the ground and lifted into place, usually with the help of a crane. The whole process is best left to professionals, but does not typically require any special training (Gipe, 1993).

5.2. Safety Concerns

There are a number of safety concerns associated with SWECS construction. Most of these concerns can be easily met. There is no reason for considering SWECS as hazardous (Lawless-Butterfield. 1981). That said, it is important to consider safety at each point in the development of a wind turbine. This begins in the design of the turbine and the tower. Engineers must have a firm understanding of the maximum loads various components of the system will see over a life-time of use. Typically engineers have very good access to information and carry out their job of designing a safe structure professionally. It may be beneficial to test a wind structure. Most of this testing can be done by the manufacturer rather than the end user (Jackson, 1995). There are very few reports of structural failure of SWECS or any wind turbine that pose a safety risk. However if SWECS are to be widely implemented it is important that codes be developed to insure that safety is a primary consideration in the process of construction. Such standards are beginning to see development in Europe (Stam. 1984).

6. Maintenance

6.1. Reliability

Obviously a wind machine is not effective if it is not turning in the wind. Furthermore it loses it’s effectiveness if a gear train is stripped. Plagued by such mundane problems wind farms have had to deal with operational efficiency decreases of up to 30% (Spera. 1994). Clearly reliability is an important factor in a wind machine’s overall operational efficiency. The primary wear that a wind machine experiences is due to the rotation around it’s axis. SWECS must rotate many more times than larger wind machines to maintain efficient tip speeds. This means that wear is a potentially more serious problem for these small machines. On the other hand, small machines tend to have lighter axles and operate at lower torques, two considerations that minimize the potential of wear.

Once a wind machine has been installed, there are no fuel costs associated with it’s operation. Therefore the costs of wind power, unlike other sources of electrical power, are almost entirely due to the initial capital costs. Early economic models aimed at determining the feasibility of wind-derived power ignored any other costs. Clearly this is an oversimplification. Although capital costs are by far the largest of the costs associated with wind power, maintenance costs are far from negligible. As would be expected maintenance costs vary wildly and are dependent on such factors as machine manufacturer, machine design, machine age, type of wind that passes over a site, exposure to harsh weather (rain, snow, ice, dust), skill of laborer, equipment available to those carrying out repair, and access to site. A more detailed economic consideration will be carried out elsewhere in this paper.

There is a deficit of published information about the maintenance necessary for small wind turbines, but information is available from various manufacturers. Larger wind farms have more detailed records regarding maintenance, some of which has been published. One of the greatest concerns about maintenance when considering small wind turbines is not the cost but rather the inconvenience and/or dangers associated with various repairs. It is hard to imagine that many homeowners would opt for an alternative electricity source that requires them to climb 100 ft. into the air periodically to overhaul a turbine's bearings when they are accustomed to hassle-free electricity from a remote power plant. Despite being generally overlooked by researcher, there are some recent projects that are aimed specifically at developing low-maintenance wind turbines.

6.2. Lessons from Large Wind Farms

There are many lessons to be learned from the operation of large wind farms. Many early farms saw higher than expected maintenance costs, leading to complete retrofits of existing wind power (Anonymous. 1987: Anonymous. 1986: Gipe. 1986). Typically wind farms have seen maintenance costs account for 15% of the overall investment (Gipe. 1988).

Operation and maintenance (O&M) for gas, cogeneration, and coal plants may be a chore. For wind farms the difficulties rise exponentially. The systems are complex, spread over large areas, often difficult to access, and in most cases must be worked on in situ, under many weather conditions (Burton. 1996). On the other hand wind machines benefit from serial production. Much learning has taken place, and most modern wind farms are no longer plagued by the problems that threatened to shut them down in the 1980s. Sophisticated techniques are now used to identify and eliminate operational problems (Iniyan. 1996). Still, if the experience of large wind farms is any indication, owners of wind machines should expect occasional repairs, constant maintenance, and infrequent retrofits or upgrades if they plan to keep their wind machines operating at maximum efficiency (Marier. 1981 and 1985).

In recognition of the seriousness of maintenance and reliability issues, exciting new research has been presented in recent years. Leveraging the inherently modular nature of wind turbine technology, a new type of wind turbine has been proposed (Weisbrich. 1996). Other developments aimed at improving serviceability and/or reliability include new generator designs and low friction axles (Soderlund. 1997). There has been an effort to develop “autonomous” or maintenance free wind machines (Neris. 1995: Valtchev. 2000). It is too early to determine the future success of such projects, but the prospects are encouraging. One innovation that has been widely adopted by the SWECS industry is incorporation of closed bearings in the manufacture of SWECS. This move eliminates the cumbersome and time consuming task of greasing and overhauling wind machine bearings, a process that at one time had to be performed once a year (www.awea.com).

7. Economics

The economic viability of SWECS depends greatly several site-depended factors. (1) The quality of wind resource is perhaps the primary determining factor of the viability of a wind tower. The power output increases roughly as the square of the wind speed, so the difference between a 10 mph and 12 mph site is a dramatic 50% increase in power available (Gipe. 1993). (2) The availability of a grid-connection can have a large influence on the costs associated with wind power. With a grid-connection expensive batteries or diesel back-up are not needed. (3) The accessibility of a given site will have a large impact on maintenance costs. (4) The reliability/availability of a given wind turbine will determine how often it operates, and hence to overall operating efficiency of the machine.

7.1. Conditions of Economic Viability

Despite these variables the costs of a SWECS can be fairly accurately modeled using some estimations and assumptions. The US Department of Energy offers the following guidelines in determining whether SWECS make financial sense (www.doe.com):

- Wind Speeds should be at least 10 mph (4.5 m/s)
- Utility-supplied electricity is relatively expensive (10 to 15 cents/kWh)
- Utility’s requirements for connecting to the grid are not prohibitively expensive
- Local building codes allow legal erection of a turbine
- Long-term investments are compatible with your financial situation

While these general guidelines are helpful in determining eligibility for SWECS, each case requires a more detailed economic analysis during the planning process. Typical numbers published by SWECS manufacturers (see Appendix B) suggest that for the average consumer the cost of purchasing, installing, and maintaining a grid-connected small wind turbine is paid down after 4-9 years of operation. This makes the investment in an SWECS very attractive to those who foresee retirement in coming years. The promises of an inexhaustible power source at a fixed price is very compatible with those living on a fixed, declining, or variable income.

7.2. Dynamic Economic Analysis

A more sophisticated dynamic cost analysis can be applied when large-scale implementation of wind turbines is considered. Because of their highly module nature, wind turbines stand to benefit from technical breakthroughs associated with serial installation. Experience curves can be applied to the development of wind turbine technology including increased reliability, decreased maintenance costs, increased installation efficiency, increased operational efficiency, and decreased per unit cost. Experience shows that the cost per unit can be decreased by serial production. This learning curve can be described by Equations 1 and 2(Peters et al. 2001)

$$C_N = C_1 \cdot N^{-\alpha}$$ **(Equation 1)**

where

$$\alpha = -\left(\frac{\ln \frac{f}{100}}{\ln 2}\right)$$ **(Equation 2)**

and C_1 is the cost of the first power plant, C_N is the cost of the *N*th plant, *f*/100 is the progress ratio (the 2nd unit is *f* percent as expensive as the 1st). Recent dynamic analysis of wind turbine development has shown that given the current trends in wind number of installed units, the costs of turbines installed in 2020 will be half the current cost of installation (Neij, 1999).

7.3. Forces Driving Use of Large-Scale Wind

The effects of learning the result from serial production are balanced by economies of scale. Economy of scale can be described by Equation 3 (Peters et al. 2001):

$$\frac{C_i}{C_o} = \left(\frac{K_i}{K_o}\right)^n$$ **Equation 3**

where C_i is the cost of size *i* and C_o is the cost of a reference size, K_i and K_o are the sizes of a reference and *i*th plant, and *n* is a scaling exponent, typically ~2/3. In words, this equation states that the cost is inversely proportional to the size (“bigger is better”). This effect works in favor of large wind machines (which is a primary reason why the current trends favor behemoths) and against small wind machines.

7.4. Busbar Pricing

Another factor in favor of the development of small wind turbines is the fact that by PURPA most utilities have to buy back electricity from a unit such as a SWECS at “fair” prices. “Fair” tends to be with regards to the price consumers are charged for electricity rather than the busbar pricing. Therefore the electricity generated by a SWECS is many times more valuable than that generated on a wind farm (which must compete directly with the very low busbar price of fossil fuel-based electricity). It a SWECS is being used to displace electricity that would otherwise be purchased from the grid, the value is even higher. For example, busbar prices are commonly as low as 4 cents per kWh while consumer prices might be 14 cents per kWh. This 3 fold increase in value means that effectively 1/3 as much electricity must be produced for the same economic effect (Gipe, 1993).

8. Conclusions

Obstacles to the implementation of SWECS, often shrugged aside by die-hard proponents of renewable energy, must be addressed before this technology can find widespread acceptance. There are plenty of reasons why SWECS should be pursued. Small wind turbines share many of the advantages large turbines offer – zero emissions, no fuel costs, minimal environmental impact—and offer a few of there own. Advocates rightly point out that small-scale wind machines have the potential to play an important role in the electricity grid. Benefits include increased grid stability, increased grid capacity, and decreased load on the grid. At the same time, consumers of electricity are brought to the position of supplying electricity. This cultural shift has the potential to encourage more efficient use of electricity and greater conservation. A homeowner with a SWECS need not worry about fluctuations in the energy market, making this technology well suited to those on fixed, variable, or declining incomes. SWECS are also well suited to contribute to the movement towards zero-net emission buildings.

Despite the attractive qualities of SWECS there are good reasons why this technology has not found widespread use. Implementation of SWECS must overcome a number of obstacles. Atop the list are concerns about availability and reliability. However mundane, maintenance may be the Achilles’ heal of today’s SWECS. Though there are no costs associated with the “fuel” for wind power, the costs are operation are not negligible. A great deal of learning has taken place as the technology of modern wind turbines has matured. The serious issues of reliability that threatened wind farms in the 1980s have been dealt with, and much of this learning has trickled down to the development of small wind turbines. Innovations such as the use of closed bearings promise that the upcoming generation of wind machines will need far less attention than those of the past. At the same time there is room for further technical advances. Though the aerodynamics of large turbine blades have undergone significant revision in recent years, small blades still waiting to be directly addressed. Great advances in the reliability of wind machines could be made by reducing the operational complexity of the machines.

Local zoning issues will always be a barrier to the implementation of wind turbines large and small. There are steps that could be taken to standardize the safety, and building specifications of these machines that would go a long way towards streamlining the zoning process. In addition to an organizational approach, there are technical advances that may lead to more aesthetically pleasing wind turbines. This issue may further benefit from public education. A good deal of path paving has been carried out by the cellular communications industry and cross communication and sharing of knowledge between the two industries could be very beneficial.

The obstacles facing widespread implementation of SWECS are not insurmountable. However they must be faced head-on if the technology will take-off. Addressing the impediments to SWECS installation will require a combination of technical, organizational, and cultural advances.

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