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AN INTRODUCTION TO THE SMALL WIND TURBINE PROJECT

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ABSTRACT

Small wind turbines are typically used for the remote or rural areas of the world including: a village in Chile; a cabin dweller in the U.S.; a farmer who wants to water his crop; or a utility company that wants to use distributed generation to help defer building new transmission lines and distribution facilities. Small wind turbines can be used for powering communities, businesses, homes, and miscellaneous equipment to support unattended operation. This paper covers the U.S. Department of Energy/National Renewable Energy Laboratory Small Wind Turbine project, its specifications, its applications, the subcontractors and their small wind turbine concepts.

SMALL WIND TURBINE MARKETS

Small wind turbines are used throughout the developed and developing world and are primarily used in rural or remote settings in the domestic and international markets. Small wind turbines can be used to power communities, businesses, schools, clinics, single households, farms and a variety of equipment. Small wind turbines can be developed to meet the specifications suitable for the domestic and international (developed and developing) markets.

Domestic Markets
In the United States, 24% of the population lives in rural areas and a growing number live remotely. Most of those individuals have access to the grid, but there is a group of customers where the cost to connect with the utility grid is prohibitive. For those off-grid individuals, diesel generation systems, renewables (solar, wind), and a storage device (batteries) used in combination as a hybrid power system could provide a solution.

International Markets
Currently, 50% of the international rural sector (not necessarily agricultural) population does not have electric power.[1] An estimated 2 billion people do not have access to electricity. This figure is projected to increase to 3 billion by the year 2030. Within the international market, there are two market groups: the developed countries and the developing countries. In the Organisation for Economic Cooperation and Development (OECD) nations or developed countries, electric needs are met with a mature market, with developed infrastructure and a stable population. OECD nations will experience slow growth in the power market, estimated to be at 0.7%/year.[2] OECD countries have typical needs for grid-connected technology, which makes this market similar to the domestic market.

In developing countries, energy needs are driven by migration to urban areas, growth in per capita income, increased use and manufacture of energy intensive products, and poor efficiency in providing power. Worldwide growth in energy services is expected to be seven times that of the OECD countries (5.3%/year).[3] The World Bank has estimated that within 15 years, the total energy consumption will be greater in the developing world than in the OECD countries. "At present, in some developing countries, between one-third and one-quarter of available public resources are going into the electric power sector, and these investments are still inadequate. The aggregate investment demand for electricity in the developing countries is U.S. $100 billion over the next decade." [4]

SMALL WIND TURBINE PROJECT

The Department of Energy added the Small Wind Turbine project to the Turbine Research program in 1995 to stimulate the application of advanced technology in that portion of industry that serves specialized markets requiring wind turbines in sizes from 5 to 40 kW. Such systems are deployed in a wide range of commercial applications, often high value end-use applications in remote sites that require high reliability over extended periods of unattended operation.

The goal of the Small Wind Turbine project is to help U.S. industry develop cost-effective, high reliability small wind turbine systems for both the domestic and international wind energy markets. The objective of this project is to provide tested small wind turbine systems, sized from 5 to 40 kW (maximum power), that meet a Cost/Performance Ratio of $0.60/kWh or less at 5.4 m/s (12.1 mph) sites and significantly reduce the cost of energy by the year 2000. The systems are also expected to meet certain design requirements such as: high reliability, ease of transportation and installation, low maintenance, International Electrotechnical Commission (IEC) Class II requirements, and environmental considerations (desert, coastal, cold weather) based on specific markets.

The scope of work emphasizes an iterative engineering development process, including formal design reviews at the end of each project stage and tests to verify the system design and analyses (see Figure 1).

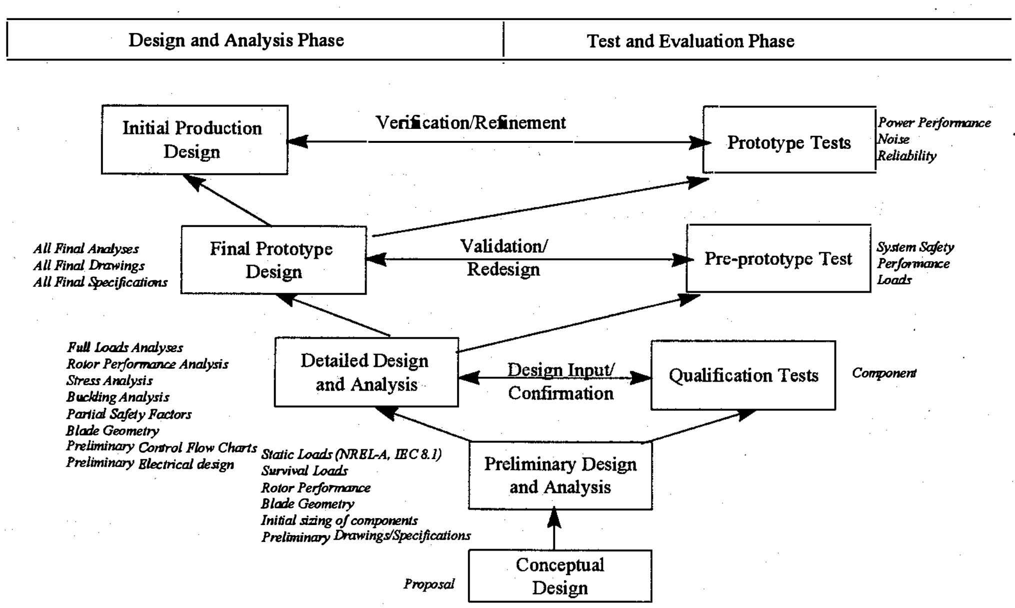

FIGURE 1 - SMALL WIND TURBINE ENGINEERING DEVELOPMENT PROCESS

The first stage will develop a preliminary design for the prototype turbine based on the subcontractor's market assessment and proposed concept. Stage two will generate detailed designs of components and subsystems, which will be verified through qualification tests. Information obtained in the design process and qualification tests will be integrated into a pre-prototype turbine design. Stage three will fabricate and test the pre-prototype turbine at a site chosen by the subcontractor to validate the operational, safety, and structural characteristics of the system design. Pre-prototype test results will be used to refine the system design, as necessary, to complete a final design for the prototype turbine. Stage four will upgrade the pre-prototype test turbine to the final prototype configuration. The prototype turbine, which is the definitive product resulting from the Small Wind Turbine project, will be field tested for 1,000 run-time hours at the National Wind Technology Center (NWTC) to evaluate system performance and reliability. During this 1,000 hour run-time test, the turbines will be tested to meet certain IEC testing requirements including: power performance (IEC 1400-12), and acoustics (IEC 1400-11), as well as reliability inspections and loads measurements. After installing the prototype turbine at the NWTC, the subcontractor will document the final design and analyses in preparation for certification and production. Final drawings, engineering specifications used to procure and inspect components, and bills of materials will be developed in order to completely document the resulting engineered product. The anticipated period of performance for these subcontracts is 36 months.

SPECIFICATIONS

Specifications listed in the Request for Proposal (RFP) include: 5-40 kW maximum power; high reliability; low maintenance; ease of installation and transportation; identification of extreme environmental considerations (coastal, desert, cold weather); a cost performance ratio – turbine system cost/net annual energy production (AEP_{net}) of $0.60/kWh (5.4 m/s); use IEC class II guidelines (resource of 8.5 m/s, wind gust for 100 year of 132 mph) for analysis and design; and a COE that will be reduced by year 2000. Specific explanation of the market drivers for each specification (shown in italics) are provided below.

5-40 kW Size

Review of available small wind turbines data identified approximately 25 manufacturers (3 U.S. manufacturers) throughout the world that produce small electricity-generating wind turbines in the 5-40 kW rated power range as of 1996. In addition, approximately 10 wind turbines over 6 m in rotor diameter are being manufactured internationally for water pumping. Based on market potential, small number of U.S. manufacturers, and the desire to advance the technology, NREL targeted the 5-40 kW range for development.

High Reliability and Low Maintenance

This requirement of high reliability and low maintenance is driven primarily by the need to have operating wind turbine systems in remote or developing locations throughout the world. Unlike utility grade turbines, small wind turbines are typically sold in small groups or as stand-alone installations. This adds to the maintenance costs since turbines are not co-located. Maintenance could involve a trained windsmith who would have to travel potentially significant distance to maintain a few or one wind turbine system. An alternative is to get in-country support and have detailed simple instructions for scheduled maintenance and easy unscheduled maintenance. The sensitivity to high reliability and low maintenance increases as the remoteness of the location increases.

Ease of Transportation and Installation

Ease of transportation is necessary for international markets that require the use of standard shipping containers for transporting the small wind turbine systems. The primary market drivers for ease of installation are the developing countries that do not have the infrastructure (roadways, lifting equipment, and transportation systems) to support small wind turbine installation and erection. Domestic customers living in rural or remote areas may also have limited access to lifting equipment necessary for turbine erection.

Cost Performance Ratio

The Cost Performance Ratio (CPR) is an annualized figure of merit that is defined as the turbine system cost (cost of the turbine system and tower without installation) divided by the net annual energy production. It does not account for life-cycle costs, balance of station costs, or operations and maintenance costs. CPR encourages the designer to lower turbine system cost and increase annual energy production, consistent with the procurement goals and objectives.

NREL selected CPR as the primary figure of merit for the Small Wind Turbine project to compare the proposed turbine concepts and to track the development of the design throughout the project. Figure 2 shows average cost performance data for small wind turbines in the 5-40 kW size. CPR data compiled from individual turbine manufacturers ranged from 0.48 to 2.43 ($/kWh). When the data was normalized based on the rated power, as shown, CPR does not fall below the $0.60/kWh or less target (at 5.4 m/s sites) set for the Small Wind Turbine project.

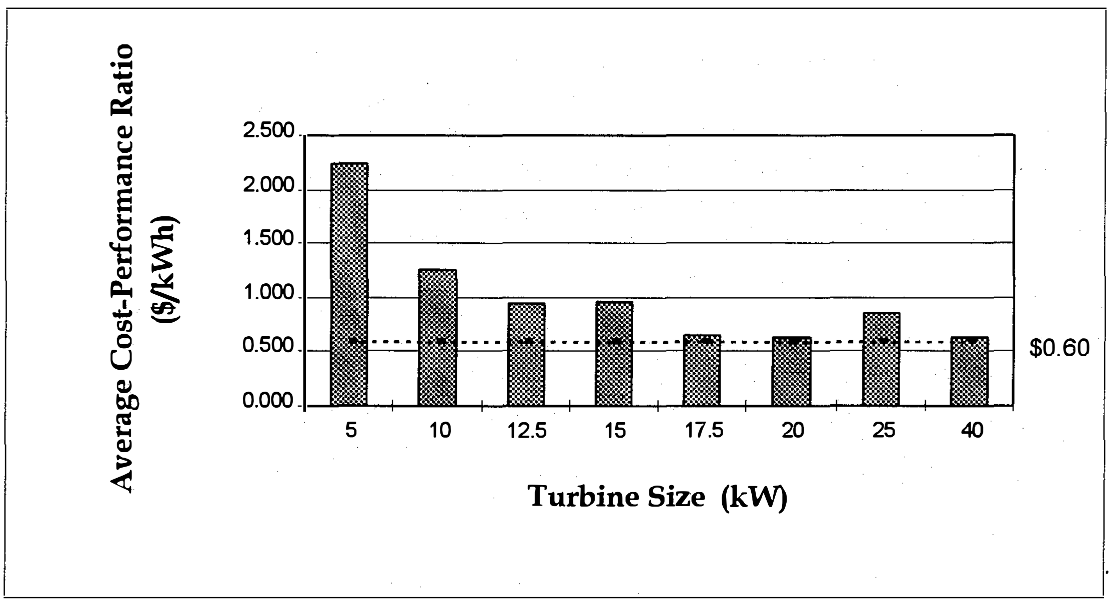

FIGURE 2 - AVERAGE COST PERFORMANCE RATIO VERSUS TURBINE SIZE (5-40 kW)

Reduced COE

The Small Wind Turbine project also requires the subcontractor to significantly reduce the cost of energy (COE) of the proposed concept, relative to the COE of its baseline turbine, by the year 2000. The life-cycle COE accounts for initial capital costs (turbine system and balance of station costs), annual operations and maintenance costs, levelized replacement costs, and net annual energy production, including losses due to blade soiling, the collection system from turbines to the grid, and miscellaneous losses.

For small wind turbines, COE varies widely depending on the application, location, and other factors, such as financing costs. Reliable cost information necessary for calculating COE is not readily available. As a result, NREL did not select COE as the primary figure of merit for this project. While the basic units of the CPR are similar to COE, the two figures are not directly comparable because COE is a life-cycle cost model and CPR is annualized.

IEC Class II Design Load Cases
Recent sales in OECD or developed countries have required certification of wind turbines. To ensure that the small wind turbine designs will be ready for certification at the end of this project, NREL has based its design requirements on IEC standards. The turbine designs must meet IEC wind turbine Class II parameters, as a minimum requirement. Class II references an extreme wind speed of 42.5 m/s or 132 mph and a minimum of a 20 year service life. The subcontractors will be required to use design load cases identified in IEC 1400-1 "Wind Turbine Generator Systems - Part 1: Safety Requirements."

APPLICATIONS

Because of the diversity of potential end-uses, proposers were asked to specify their target market and application for their turbine concept in order to fold in any requirements early in the design phase. Applications were categorized as grid-connect or constant AC load, wind electrification or variable AC load, or battery charging or DC load (see Figure 3). Combinations of applications or other applications were considered in the proposal evaluation as long as the primary output of the turbine was electricity. Grid

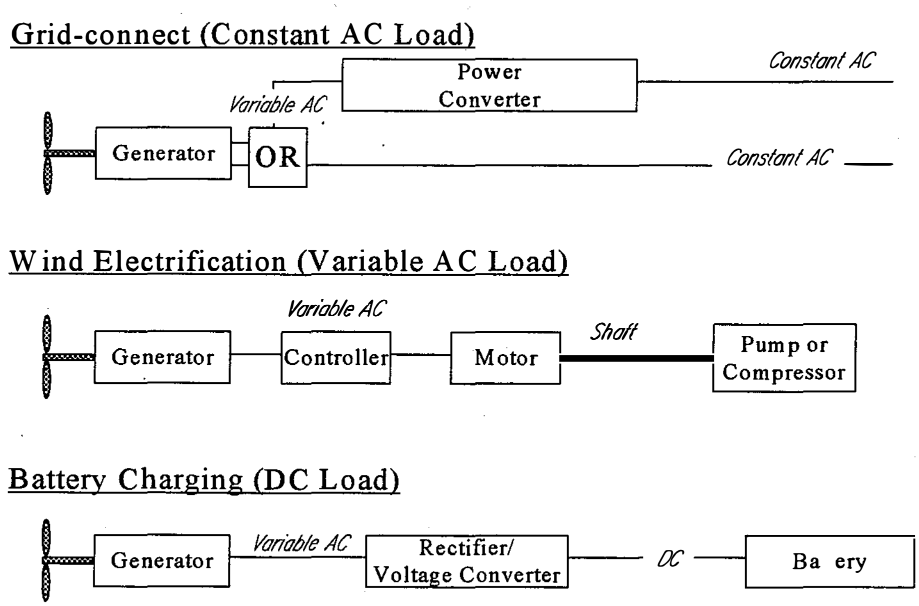

FIGURE 3 - SMALL WIND TURBINE APPLICATIONS

connect can include three-phase or single-phase electricity, and the systems could be owned by utilities, rural electrification associations, or community mini-grids (either hybrid or battery charging stations). Hybrid systems are defined as multiple power sources (e.g., wind turbines, photovoltaics, diesel generators, fuel cells) linked together to serve stand-alone or small grid electric power needs. Hybrid systems may include power electronics (e.g., rectifier, inverter), batteries or other forms of storage and dump loads. Wind electrification is power used directly to run compressors, or shafts (e.g., water pumping, ice making, stripper wells). Intermittent generation is often acceptable for wind electrification applications, so batteries or other storage are minimal if required. Battery charging is the third application sought in the RFP. Battery charging systems are used in remote applications that require continuous power, such as telecommunication stations and community battery charging stations. Dump loads are often included in battery charging systems to handle the excess power after the battery is fully charged.

The RFP was written with the above specifications and applications in mind. However, proposers could modify their specifications or applications based on their understanding of the market. The RFP was released on June 5, 1996. Responses to this request were received by September 5, 1996, and subsequent selections were made to four companies: Bergey Windpower Company; Cannon/Wind Eagle Corporation; WindLite Company; and World Power Technology, Inc. Negotiations are in process with each of the companies with subcontract awards expected in the July through October time frame.

SUMMARY OF SUBCONTRACTORS AND PROPOSED CONCEPTS

Figure 4 shows an artist's rendition of proposed concepts for each subcontractor in the Small Wind Turbine project. Three of the proposed concepts are based on a typical small wind turbine configuration (upwind, variable speed, furling overspeed control) and one concept is based on a configuration used on some larger, utility-scale machines (downwind, constant speed, overspeed control such as aerodynamic brakes or pitch).

Bergey Windpower Company (BWC) is a family-owned manufacturing and project development company formed in 1977 in Norman, Oklahoma. Their company produces three small wind turbines rated at 0.85, 1.5, and 10 kW (BWC 850, BWC 1500 and BWC EXCEL) and has sold 1,600 turbines worldwide since production began in 1980. BWC has sold its products in more than 70 countries and is well known for pioneering work in village power and pumping. Mike Bergey will be the project manager and his team will be supported by Karl Bergey, Dr. Kenneth Craig, Pieter Huebner, and Dr. Michael Selig (University of Illinois).

The proposed 40-kW concept is a three-bladed, upwind, variable-speed, furling machine that meets the market requirements for village power, primarily battery charging. The proposed rotor diameter is 14-meter with a 55-m tower, and different rotor diameters will be available to optimize performance for different wind regimes. The pre-prototype turbine will be tested in Norman, Oklahoma, followed by prototype turbine tests at the NWTC configured as a battery charger.

Cannon/Wind Energy Systems has been in the business of operating and maintaining windfarms in Tehachapi, California since 1982. During that time, Cannon has installed over 1,100 turbines and currently manages and operates 567 wind turbines manufactured by Nordtank, Micon, Vestas, and Cannon. The Cannon/Wind Eagle WE-14 team consists of Craig Loke, Fred Beasom, Jeff Wilks, Robert Ochoa and consultants including Jamie Chapman, Ruth Heffernan-Marsh, Jay Carter, Sr., Kevin Jackson, and Woody Stoddard.

The proposed 25/30-kW concept is the culmination of more than 15 years of research, design, and development of a lightweight, flexible turbine design. It is based on a scaled-down model of the 300-kW Wind Eagle utility-grade turbine which is currently under development. The concept is a two-bladed, large load-shedding 14-meter diameter rotor, downwind, constant speed, gimballed nacelle turbine with a 36.6 m tilt-down tower.

WindLite Corporation is a new corporation, but is made up of senior people with experience in the wind

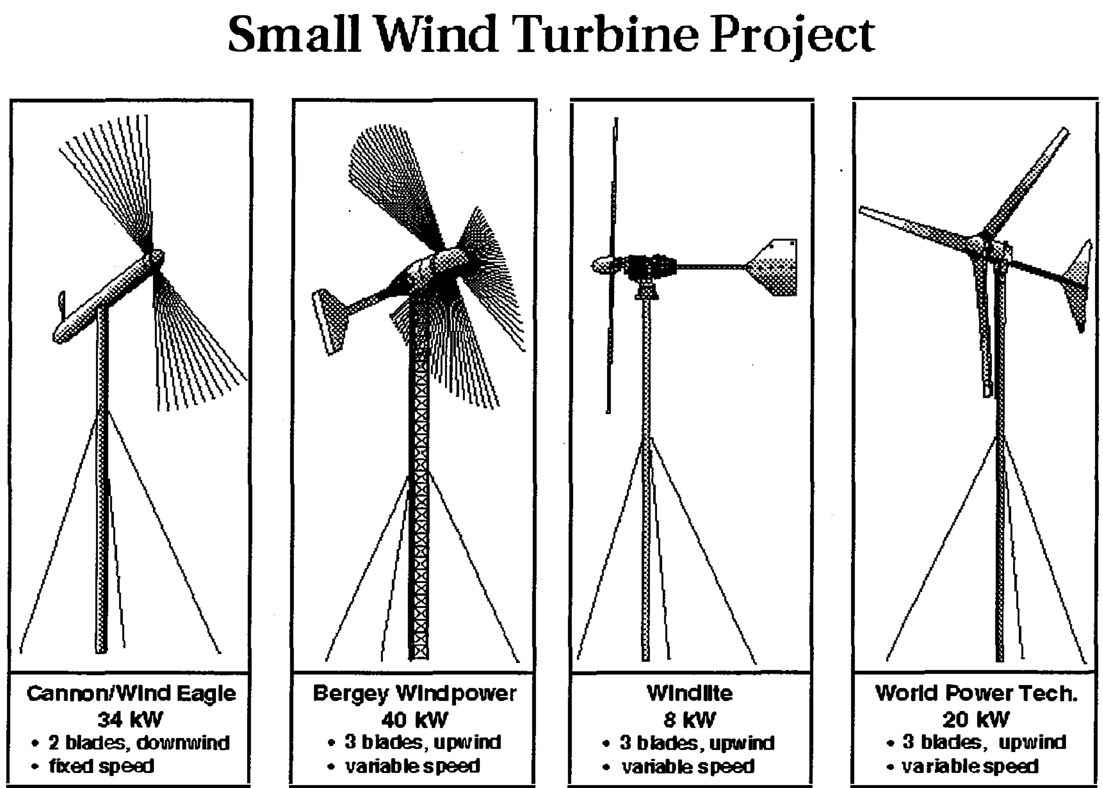

FIGURE 4 - SMALL WIND TURBINE PROPOSED CONCEPTS

energy field. Robert Lynette will act as the president and marketing director, with Jay Jayadev as the project manager and Jim Sencenbaugh as the principal investigator. The WindLite team will draw on technical resources from R. Lynette and Associates. It will also be supported by Mick Sagrillo of Lake Michigan Wind and Sun and a team of consultants.

The proposed 8-kW concept is a three-bladed, 6.7-meter diameter rotor, upwind, variable speed, furling turbine. The primary application for this wind turbine is battery charging. WindLite will perform their pre-prototype tests at Altamont Pass, close to its facility in Mountain View, California. A prototype will be tested the NWTC as a battery charger.

World Power Technology has been in business since 1974, starting with its Whisper 1000 machine which was followed by the Whisper 600, Mariner H500, Whisper 3000, Whisper 4500, and Whisper 900. World Power Technology produced its thousandth Whisper 1000 in November 1996 and has produced 2500 machines in total. World Power is located in Duluth, Minnesota, and is overseen by a board of directors that have experience in developing products for various domestic and international markets. Elliott Bayly will be the principal investigator, and Robert Clarke (President of Alpen) will be the project manager.

The 20-kW proposed concept is a three-bladed, 9-meter rotor diameter, upwind, variable-speed, furling turbine targeted for grid-connect applications. The pre-prototype will be tested at a site in Minnesota owned by World Power Technology. The pre-prototype will then be upgraded to the prototype configuration and tested at the NWTC as a grid-connect turbine.

CONCLUSION

The DOE/NREL Small Wind Turbine project will enable the U.S. wind industry, national laboratories, and consultants to pool their knowledge and develop cost-effective, high reliability small wind turbines for domestic and international wind energy markets. Four companies were selected through a competitive procurement to develop advanced small wind turbine systems for deployment in a wide range of commercial applications. The turbine designers will follow an iterative engineering development process that will include formal design reviews at the end of each project stage and tests to verify the system design and analyses. Documentation necessary for IEC Class II turbine certification will be completed by the end of the project.

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