American Wind Energy Association

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WIND ENERGY APPLICATIONS GUIDE

INTRODUCTION

Wind energy has been used since the earliest civilization to grind grain, pump water from deep wells, and power sailboats. Windmills in pre-industrial Europe were used for many things, including irrigation or drainage pumping, grain-grinding, saw-milling of timber, and the processing of other commodities such as spices, cocoa, paints and dyes, and tobacco. Before the U.S. installed an infrastructure of electricity wires, both water-pumping windmills and small wind electric turbines ("wind chargers") were vital to farming and developing the American Great Plains and west.

In recent decades, the industry has been perfecting the wind turbine to convert the power of the wind into electricity. The wind turbine has many advantages that make it an attractive energy source, especially in parts of the world where the transmission infrastructure is not fully developed. It is modular and can be installed relatively quickly, so it is easy to match electricity supply and demand. The fuel – the wind – is free and plentiful, which eliminates or reduces the need to purchase, ship, and store expensive fuels. It is flexible – with the power generated, households use can use appliances, such as lighting and refrigeration, schools can use computers and televisions, and industries can access a reliable power source. Perhaps most importantly, the generator does not produce any harmful emissions in the process of generating the electricity, unlike many other generation sources.

The use of renewables to provide power to remote villages has had a mixed record in the past because maintenance was costly and replacement parts difficult to obtain. However, due to research on very low-maintenance designs, small wind turbines are once again gaining popularity as an economical way to bring the benefits of power production to homes, villages, and industries that may be remote from an established grid or wish to operate without burning fossil fuels. Large wind turbines can be price-competitive with any other form of generating technology in good wind resource areas.

Wind energy conversion systems are available in a wide range of sizes and can fit almost any application where power is needed. This brochure is designed to briefly explain the applications for which wind power is currently best suited in international applications and provide some contact numbers for further research.

WIND POWER BASICS

When designing a wind power system, it is crucial to understand the electricity load and the available resources.

- Demand

Estimating the electricity demand means determining the maximum power to be consumed as well as the purpose to which the electricity will be put. To reduce the amount of batteries needed for electricity storage, it is helpful to combine high-quality power needs, such as for household appliances, with lower-quality applications, such as water pumping.

Daily and monthly variations, a reserve margin for system reliability, and future demand growth should all be taken into consideration when estimating the size of the system needed.

- Resource Assessment

Wind resource assessment is also important to a successful project. Small differences in wind speed can mean great differences in power output. When measuring the wind resource and designing a project, careful consideration needs to be given to the turbine's actual exposure, the influence of obstructions, and the wind resource seasonal patterns.

The 1980 DOE/PNL "World Energy Resource Map" provides a good starting point for defining resources. The wind resource information available from local meteorological sources is often taken from sheltered urban or airport sites and often underestimates actual wind resources by a large margin. For large-scale projects, site resource monitoring is prudent. For small, single-system projects, site monitoring may not be economically justified.

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- Equipment selection

In addition to the wind resource and the planned usage, the size and type of the equipment greatly affects the power output. The swept area of a turbine rotor is a function of the square of the blade length (the radius of the rotor's swept area). A modest increase in blade length boosts energy capture and cost-effectiveness.

Every wind turbine is different despite seemingly similar power ratings. Some machines are designed to operate more efficiently at lower wind speeds while others are intended for more robust wind regimes. A prospective wind power developer would be wise to investigate all the various considerations and compare the performance to existing machines. Moreover, anecdotal information and even the professional services of wind power developers may prove helpful.

The U.S. National Renewable Energy Laboratory has developed a series of computer models for designing stand-alone electric power systems. The Hybrid Optimization Model for Electric Renewables (HOMER) will design the optimal hybrid power system, given information about electrical loads, solar and wind resources, and the performance and cost of various components. The Village Power Optimization Model for Renewables (ViPOR) will design a village electrification system, given a map of a village and some information about load sizes and equipment costs. Please refer to the contacts section for information on how to access these resources.

WIND ENERGY SYSTEM COMPONENTS

A wind energy conversion system has a relatively simple construction that can be operated and maintained by the local population. The basic components are as follows:

Windmill

The main component of a wind energy conversion system is the windmill itself. A system of blades mounted on a tower is turned by the wind to either produce mechanical work directly, usually in the form of a water pump, or to use a generator to transform that mechanical work into electrical energy (wind turbine).

Windmills and wind turbines vary in size and the corresponding amount of output they are capable of producing. The output depends mainly on the size of the blades and the wind's speed through the rotor. For example, a 10-kilowatt (kW) turbine typically has a 7-meter rotor diameter; a utility-scale turbine with a 750-kW generating capacity operates with a rotor diameter of 44 meters and a 1.5-MW turbine operates with a 70-meter rotor diameter.

A 10-kilowatt (kW) turbine typically has a 7-meter rotor diameter.

Wind turbines are typically listed by size according to the potential to generate electricity in ideal wind conditions. This is known as the "rated capacity." The ability to generate electricity is measured in watts. Watts are very small units, so the terms *kilowatt* (kW, 1,000 watts) and *megawatt* (MW, 1 million watts) are most commonly used to describe the capacity of wind turbines or other power plants. Wind turbines being manufactured now have capacity ratings ranging from 250 watts to 1.65 MW.

Electricity production and consumption are most commonly measured in *kilowatt-hours (kWh)*. A kilowatt-hour means 1,000 watts of electricity produced or consumed for one hour. One 50-watt light bulb left on for 20 hours consumes one kilowatt-hour of electricity (50 watts x 20 hours = 1,000 watt-hours = 1 kilowatt-hour).

Example: A 10-kW wind turbine can generate about 16,000 kWh annually, more than enough to power a typical household. A 1.65-MW turbine can produce more than 4.7 million kWh in a year--enough to power more than 470 average households in the U.S.

Towers

To access the best wind resource, windmills and wind turbines are usually placed on high towers. Because of their lighter weight, wind turbines can use lighter-weight towers than can conventional mechanical windmills. Towers come in two main types: guyed (lattice or pole) towers and free-standing self-supporting towers. If the topography of the site will allow the space for a guyed tower, this will be the lower-cost approach.

Towers range from 12-37 meters for small wind applications and 30-75 meters or higher for utility-scale turbines. In general, the height of the tower should be 10 meters above any obstacles within 100 meters.

Hybrid System Combinations

Many electricity generation systems use more than one kind of generator, to provide a smoother supply of power. Many systems pair one or more wind turbines with a photovoltaic (solar) array, elements of passive solar heating &/or lighting, and a back-up diesel generator. Depending on the local resources, a power system can include biomass, hydro, or other generating sources in the hybrid system.

Pump/Motor

If the wind power is to be used for pumping water, the system designer must select the pump based on the pumping head and flow requirement, wind turbine electrical output, and site conditions. Submersible pumps are most commonly used for drilled wells. At low heads and for surface water sources, horizontal-axis centrifugal pumps can be used with good results.

One of the appealing factors of wind electric water pumping is that off-the-shelf submersible pumps can be used. While these units are designed to run at the normal electrical line frequency of 50 or 60 Hz, if certain precautions are taken they can be run efficiently at a broad range of frequencies.

Storage

In addition to the electricity generators most hybrid systems have components for storing power so that usage need not be determined by the time of electricity production. The most common storage device is the lead-acid battery.

If the wind energy conversion system is to pump water, the designer will need to arrange for storage of the pumped water.

Energy Converters

An electronic component to convert direct current (DC) electricity to alternating current (AC) and vice versa is necessary to shape the power from the turbine into energy that is useful for industrial &/or household appliances.

Balance of System

The rest of the system components include monitoring equipment, a device to shed excess energy produced by the system, and the wiring and the hardware needed to complete the system.

APPLICATIONS

Water Pumping

The livelihood and well-being of people, animals, and crops depends on a reliable, cost-effective supply of clean water. Mechanical wind water pumping machines have been used to pump water from wells for centuries. The technology of modern mechanical water pumpers is relatively simple, the maintenance requirements are modest, and the replacement parts are not difficult to obtain.

The mechanical water pumper is the best option in some circumstances. However, because it must be placed close to the water source, it is often unable to capture the best wind resources.

A wind electric pumping system overcomes some of the problems with the simple wind water pumper. This system generates electricity, which, in turn, runs an electric pump. Wind electric pumping systems allow greater siting flexibility, higher efficiency of wind energy conversion, increased water output, increased versatility in use of output power, and decreased maintenance and life-cycle costs.

Water Requirements

The size of the wind turbine required for water delivery depends on the average daily volume of water required, the total pumping head, the average wind speed, and the system efficiency.

Type of Use	Consumption (liters/day)
Household:	
Drinking, cooking, sanitation and other home uses	40-100 per person
Garden	25 per m^2 of land
Farm:	
Cattle, Horses	20-40 per head
Sheep, Swine	2-6 per head
Chicken	20-90 per 100 birds
Sanitation	100-500

Source: *Wind Electric Pumping Systems: Sizing and Cost Estimation*, Alan Wyatt, 1992.

- Pumping Head

The total pumping head is the sum of the static head (the distance from water level below ground to water outlet at the water storage container) plus well drawdown (the level to which the water drops during pumping) and pipe friction.

During pump operation, additional pumping head will be required due to well drawdown and frictional losses within the pipe. This additional head can be estimated at 10 to 15 percent of the static head if more accurate information is not available.

- Equipment Sizing

A wind electric pumping system should be sized according to the months of highest water demand. The following table provides a rough guide to how much water can be delivered with different rotors in various wind regimes.

	Wind Speed, m/s			
Diameter, m	3	4	5	6
1.5	60*	150	290	500
3.0	250	590	1160	2000
5.0	700	1650	3220	5560
7.0	1360	3230	6310	10900

Wind Electric Water Pumping at Ain Tolba

This wind-electric water pumping system is installed in Ain Tolba, part of the Niama Commune near Oujda in Northeast Morocco. It is a 10-kW Bergey Excel wind turbine that drives a 12-stage electric pump located in the partially buried storage tank.

Ain Tolba has a natural spring that flows under the building on the left side of the picture. The local government constructed a sump and installed a diesel pumping system many years ago. The one pump at Ain Tolba supplies water for four communities over an area of 120 square kilometers.

While the government installed the diesel pumps free-of-charge to the local people, the users are responsible for operating and maintenance costs. At Ain Tolba the villagers could only afford to operate the diesel pump 2-4 hours per day. This meant that over 80% of the available clean water from the spring was lost (it ran into a polluted stream). At Dar el Hamra, the diesel had been broken for several years so the villagers at Rmilat had to carry water 4.5 kms. [The Ain Tolba pump building contained five broken diesels and one working one at the start of the wind project.]

In 1989 the U.S. Agency for International Development (US-AID), working through the Moroccan renewable energy agency (CDER, Marrakech) and the local water department (DPA, Oujda), funded the installation of the wind electric pumping system. Due to the variability of the wind a new 50 m_3 storage tank was installed at the Ain Tolba spring site, allowing spring water to be captured continuously and pumped out to the larger tank and distribution system when the wind is blowing. At Dar el Hamra, the wind system supplied the village of Rmilat with water for the first time in years.

The systems have performed well and the area now has three times as much water as it did using the diesel. The local population is up and commune members are actually selling water to neighboring towns. Additional smaller wind systems, both for pumping and electricity, have been installed in the area.

Stand-Alone Systems for Home and Business

In many places, wind power is the least-cost option for providing power to homes and businesses that are remote from an established grid. Researchers estimate that wind produces more power at less cost than diesel generators at any remote site with an average wind speed greater than about 4 meters per second. The applications for electricity in households range from operating small household appliances to refrigeration and freezing, heating, cooling, and lighting.

The accompanying table gives a representative idea of the power requirements of some household appliances.

Item Description	Power, watts	Daily Energy, watt-hours/day
Incandescent Light	60	180-720
Fluorescent Light	15	45-180
Radio	5-15	20-100
Television	15-100	30-600
Refrigerator	80-500	2,000-10,000
Village Household	60-300	300-1,200

Wind turbine performance depends primarily on rotor diameter and wind speed.

The accompanying table gives an estimate of a wind turbine's output, based on wind speed and rotor diameter, in watt-hours/day.

	Wind Speed, m/s			
Rotor Diameter, m	4	5	6	7
1.5	35	70	94	117
3	152	269	386	468
5	421	761	1053	1287
7	831	1522	2107	2575

The amount of power that a turbine produces depends heavily on the wind speed at the turbine height. System designers must weigh improved performance of the wind turbine at higher tower heights against the increased cost and difficulty of installing higher towers.

Inner Mongolia Household PV/Wind Hybrid Systems Pilot Project

The Inner Mongolia Autonomous Region has been working in the past decade to provide stand-alone renewable power systems to area households. Over the past decade, more than 120,000 households have started generating electricity with 100-300 watt wind generators. By the year 2000, the New Energy Office of IMAR plans to install 25,000 remote household systems using wind, PV, and wind/PV hybrid systems and in the longer term a total of 80,000 systems throughout IMAR.

In the first phase of the cooperation in IMAR, the University of Delaware, the U.S. National Renewable Energy Laboratory, and the Inner Mongolia team completed a levelized cost analysis of rural electrification options for several counties. The following table explains the findings. For the types of systems currently being deployed for stand-alone electrical generation in rural areas of IMAR, wind generators are the least-cost option for household electricity in the four counties.

System	Output Range (kWh/yr)	Levelized cost from field analysis ($/kWh)
Wind only	200-640	0.50-0.63
PV only	120-240	0.77-0.83
Small hybrids	400-750	0.57-0.72
Large hybrids	560-870	0.43-0.57
Diesel Gen-sets (not continuous)	660-730	0.76-0.80
Diesel Gen-sets (continuous cycle)	480-560	1.16-1.27

Systems for Community Centers, Schools, and Health Clinics

A larger system can provide power to a centralized community center, health clinic, or school. A power system for a health center can enable the storage of vaccines and radio communication for emergency calls. A power system for a school can provide electricity for computers and educational television, video, and radio. Community centers often find that, in addition to the benefits of the power, such as lighting and cooling, the "waste energy" can be used to charge batteries or make ice for sale to households.

Extending the distribution lines to individual homes and creating a "mini-grid" increases the convenience of the power system to the community.

The United States' National Renewable Energy Laboratory is involved in exploring a new concept that may significantly lower the cost &/or improve the performance of village systems: the "high-penetration" diesel retrofit system. A substantial amount of diesel fuel could be saved with a control strategy and system architecture that allows shutting down the diesel generator when the wind is sufficient to carry the load, and uses short-term battery storage to reduce diesel start-ups during instantaneous lulls in the wind.

The energy requirement and equipment size calculations are similar – on a larger scale – to those for the stand-alone system. The best-designed systems will use as much power as possible directly, instead of storing it in batteries. This reduces initial cost and complexity while delivering the wind's energy in the most efficient way. Using some or all of the turbine's output to pump water, grind grain, or run other loads not dependent on utility-grade electricity reduces the need for batteries for storage of constant-frequency AC power.

Hybrid System in Atulayan Island, Philippines

Atulayan is a small isolated island in Camarines Sur, Philippines, about 3 km. off the beach of Nato, a larger island. Living on Atulayan are some 100 families deriving livelihood from fishing and seaweed farming.

The Camarines Sur IV Electric Cooperative Inc. (CASURECO IV) spearheaded the installation of the hybrid power system in Atulayan. The system was sized to supply an average of 36.5 kWh/day, with a peak load of 11.5 kW, enough to provide electricity for lighting and appliance use in 72 households (compact fluorescent bulbs, color TVs, radios, electric flat irons, and karaokes), a school (lights and a computer), streetlights, and the village playground (lighting during fiestas). Supply of electricity to a seaweed dryer supports the livelihood of the village's seaweed farmers.

With the integration of inverters and a battery bank, the village is able to enjoy grid-quality 24-hour AC power, 220V single-phase and 380V three-phase. Since the system was developed specifically for remote areas, it has automatic start-stop controls and easy operation and maintenance procedures. The villagers themselves are responsible for day-to-day management and operation of the system.

System Specifications

1 x Synergy S20000 wind turbine (48V) & 24 m tilt-up tower, w/ lightning protection
3 x 5.5 kVA sine wave interactive inverter, tropicalized
1 x 48 V battery bank 2000 Ah (C20) and battery racks c/w maintenance kit
1 x Synergy 40A control box
12 x 75Wp solar panels c/w pole mount array frames and wiring
1 x 75 kVA gen set (retrofit of existing Atulayan unit, thus oversized)
1 x genset controller
1 x system wiring and earthing kit plus DC panel
Note: (CASURECO IV provided the powerhouse, power and distribution lines.)

Industrial Applications

The number of dedicated industrial applications for wind power continues to grow. Small wind power systems are ideal for applications where storing and shipping fuel is uneconomical or impossible.

Wind power is currently being used for the following applications:

- telecommunications
- radar
- pipeline control
- navigational aids
- cathodic protection
- weather stations/seismic monitoring
- air-traffic control

Wind machines in industrial applications typically encounter more extreme weather than home power systems and must be designed to be robust with very minimal maintenance.

Seismic Monitoring Sites in Antarctica

In January, 1999, Northern Power Systems installed two hybrid power systems for seismic monitoring sites for on the continent of Antarctica for the United States Air Force.

The system requirements for the project were formidable: it called for 100% system reliability, a design capable of withstanding wind loads in excess of 200 miles per hour, and the interior temperature of each shelter had to be maintained at or above 50 degrees F, while exterior temperatures could reach as low as –70 degrees F.

One of the systems included dual diesel generators with a 2.2-kW solar array on the roof of the shelter. Batteries store the excess power. The other system consists of a single diesel generator, a 3.3-kW solar array, and Northern Power Systems' HR3 wind turbine. Since the sites are only accessible about 3 months out of the year, the systems required complete remote monitoring and control capability.

After one year of operation, Northern Power Systems visited the sites to perform some routine maintenance and preplanned system upgrades. Northern attests that, despite being in one of the harshest environments in the world, both systems continue to perform well.

Grid-Connected Power

The cost of utility-scale wind power has been steadily declining throughout the last decade. Today, in good wind regimes, wind power can be the least-cost resource. Thanks to these positive economic trends and the fact that wind power does not produce any emissions, wind power has been the fastest-growing energy source in the world for the past few years. Wind power can help diversify a country's energy resources and can bring construction and maintenance jobs to the local community.

In large-scale wind power applications, there are two keys to developing the most cost-effective projects: wind speed and project size. Since the power output is so highly dependent on the wind speed, differences in one meter per second can mean differences of a cent or more per kWh in the cost of electricity production. Wind projects are also subject to scale economies. In general, given the same wind speed, a large project will be more cost-effective than a small one.

Tierras Morenas, Costa Rica

In August of 1998, Zilkha Renewable Energy, in partnership with Boston-based Energia Global, acquired all rights to the 24 MW Tierras Morenas windfarm project.

Located near Lake Arenal in the Guanacaste province, Tierras Morenas features one of the world's truly outstanding wind resources. Annual production is projected to be up to 80,000 MWh's per year. All electricity is sold to the Costa Rican state-owned utility ICE under a long-term power purchase agreement. Zilkha Renewable Energy, EGI, and a Costa Rican partnership organized a consortium of five Central American banks and the Central American Bank for Economic Integration to provide financing to the project. The government of Denmark provided substantial support to Tierras Morenas through DANIDA.

The $35 million project features 32 NEG Micon 750 kW model turbines. Constructed during the first half of 1999, the project commenced selling power in July of 1999. Tierras Morenas is the largest wind energy plant in Latin America.

CONTACTS

For more information, please contact:

American Wind Energy Association
(see back page for contact information)

National Renewable Energy Laboratory's
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Small Wind System Manufacturers:

Atlantic Orient Corporation
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515 116th Avenue, NE, Suite 263
Bellevue, Washington 98004

For further research, you may want to read the following documents, available from AWEA:

Wind Electric Pumping Systems: Sizing and Cost Estimation, Alan Wyatt, 1992, AWEA.

Wind Power for Home and Business, Paul Gipe, 1993.

WIND-DIESEL SYSTEM FOR A REMOTE STATION IN ANTARCTICA

Since January of 1985, the National Science Foundation's Black Island satellite earth station has been powered by a hybrid MicroGrid™ power system which was designed, supplied, and installed by Northern Power Systems. The unmanned Black Island site was selected to provide year-round satellite communications with the outside world for the U.S. McMurdo Station. Because the McMurdo Station cannot "see" the communications satellite due to Mount Erebus (elevation 12,448') which towers behind the Station, the Black Island facility provides a terrestrial microwave link to the station.

Black Island is located 20 miles from the McMurdo Station and is only accessible by helicopter or a dangerous two-day traverse over the Ross Ice Shelf. The harsh conditions at Black Island, coupled with the difficult access, encouraged the NSF to consider an alternative to the typical diesel-only power solution, which requires frequent maintenance and refueling.

The traditional approach to supplying power for applications which are not connected to a utility grid is to install primary engine generators which run continuously to meet the load requirements. This approach, however, results in excessive fuel consumption and inefficient operation, as well as frequent maintenance and refueling requirements. Continuous engine operation also leads to environmental concerns such as noise pollution, toxic emission, and the possibility of fuel spills.

The goal of a MicroGrid system is to minimize the run time of the back-up fossil fuel generator, thereby driving the system lifecycle cost down by dramatically reducing the amount of fuel consumed (particularly important at remote sites where the price of fuel delivered can run upwards of $4-5/gallon). The fossil fuel genset (most often a diesel genset) is always available on demand for those situations, which might require peak power output, or in those cases where renewable energy sources have not been available (i.e. cloudy, windless days). A MicroGrid system guarantees reliable power is always available: 24 hours a day.

System Design:

The initial system selected consisted of a North Wind® HR3 wind turbine (3 kW peak) manufactured by Northern Power Systems coupled with a 1.2-kW Ormat closed cycle vapor turbine generator. Both of these power sources charged a 24 VDC battery bank with the entire system managed by a Northern SC-374 system controller.

The power requirements of the Black Island site have steadily increased as the communications capabilities of Antarctic facilities have been expanded. The site now also supports a NASA tracking station. Northern Power Systems has been repeatedly contracted by Antarctic Support Associates (ASA), the NSF's prime contractor for Antarctica, to upgrade the site by supplying additional power components and systems integration. The Black Island site includes satellite earth station terminals, terrestrial links, and both fixed and mobile HF radio receiving equipment.

The final power system for the site consists of four North Wind® HR3 wind turbines, three diesel gensets, and a 7.8-kW photovoltaic array, all controlled by a Northern™ SC-400 advanced system controller. The addition of the photovoltaic array is significant in that it highlights the expense and undesirability of fuel handling and delivery in Antarctica. Even though the site is in total darkness for several months each year, the photovoltaic array is cost-effective compared to the delivered cost of fuel at Black Island. System intelligence is supplied by a custom-designed programmable logic controller manufactured by Northern Power Systems.

Performance:

Even though environmental conditions at Black Island are among the worst in the world, with documented wind speeds up to 197 mph and minimum temperatures as low as -70 degrees F, the system has not had any downtime, as of April 2001, since the winter of 1985. The renewable energy based MicroGrid power system for Black Island demonstrates the NSF's commitment to protecting the unique environment on the Antarctic continent and to reducing the impact of man on this fragile ecosystem. At the same time, no sacrifice in system reliability results from this primary reliance on clean renewable energy power sources. In another Polar Technologies project, an HR3 wind turbine installation is also part of a two-year program investigating the practicality of integrating renewable energy sources into the infrastructure of the South Pole Station, which is operated by NSF.

WIND-DIESEL VILLAGE ELECTRIFICATION

In the Northern Territories of Russia, about 20 million people live without access to an electricity supply grid. Diesel and gasoline power stations provide the main source of energy supplying the Arctic coast of Russia. There are more than 5,000 of these in total serving an annual fuel consumption approaching 6 million tons. More than 60,000 people in Russia rely on this fuel-supply network and a significant expenditure is incurred every year on fuel delivery charges to the power stations alone. Moreover, short Arctic summers, insufficient funding , and other problems threaten the stability of fuel transportation.

On the other hand, Northern Russia has excellent wind and biomass resources.

System Design:

Until now, diesel- and gasoline-powered generators have served as the only power sources in this area and because of fuel shortages, operators have usually run the generators for a few hours a day. The hybrid wind-diesel systems, however, will allow them to save significant amounts of fuel while increasing the number of power supply hours.

Two hybrid systems were installed in Krasnoe village in the Arkhangelsk region in September 1997 under the supervision of Bergey technicians. The operation of these systems so far has demonstrated the reliability of the chosen system's configuration.

It consists of two 7.5-kW turbines on 24-m (80-ft) tilt-up towers, a 48 VDC battery bank, three 4.5-kW Trace inverters, and associated switchgear. The system works with the existing village diesel generator to provide 24-hour power with a minimum of diesel fuel consumption. The Bergey team provided two-week installation, operation, and maintenance training for local engineers and technicians in 1997. The BWC wind turbine designs allow batteries to be charged in remote locations. The batteries can operate dc loads directly. With stand-alone inverters (supplied by Trace Engineering), they can provide single-phase or three-phase power for ac loads.

The Bergey units are equipped with voltage control systems (VCSs) which use solid-state electronics to monitor the battery voltage.

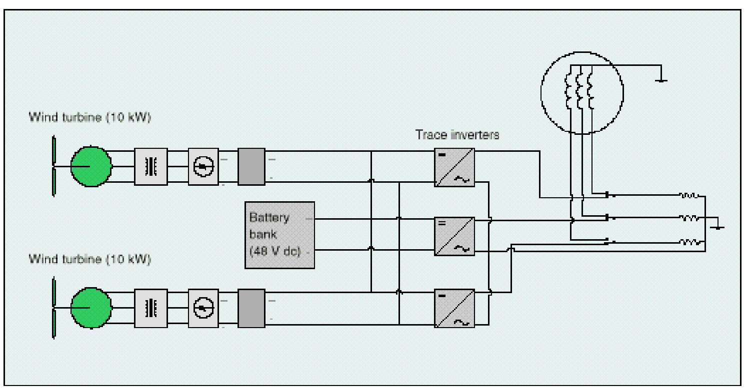
When the battery voltage reaches a preset level, the VCS unit reduces the current delivered to the batteries from the wind turbine, thus avoiding battery overcharge.

Trace inverters provide parallel operation with diesel generators. They have a variety of operating modes,

including an automatic
transfer from inverting to battery-charging, diesel start-up, and peak load shaving.

Performance:
The site conditions in the winter are quite harsh, with temperatures reaching - 40 degrees F. The system has worked without any problems since installation. NREL has installed performance monitoring instrumentation to assist MFE planners in evaluating the systems.
The US National Renewable Energy Laboratory (NREL) has purchased several sets of monitoring equipment. This equipment has
been purchased and installed on several wind-diesel hybrid systems to monitor system performance. The results will be used to optimize system control algorithms, as well as for economic analysis. These results will also be taken into consideration when designing the plans for the electrification of thousands of villages and settlements in Russia's Northern Territories.

Current performance data and possible fuel savings are given below.



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