Photo by Jim Waldon, Windmill Photography

At Last...

Simple Wind Grid-Tie

Bernd Geisler

We get more sunshine here in northern Texas than anyone may want. Wind often blows steadily for days and can sometimes get fierce. Wind speeds can go from 30 to 70 mph (13 to 31 m/s) within seconds. Twenty miles down the road, a truck loaded with scrapped cars was blown over and off Highway 75 last year by a severe gust!

Wind comes predominantly from the south in spring, summer, and fall, and from the north during the short winters. According to the maps, Grayson County lies within Wind Class 2 and borders on Class 3. A 10.8 mph (4.8 m/s) average wind speed makes it a decent area for a small wind generator.

So why doesn't anybody make use of wind and sun here? The answers are cheap oil, cheap electricity, ignorance, and negligence. Some efforts had been made, but none of the five small wind generators I've seen in our local area in the last few decades are still in operating condition.

Our grid-tied wind-electric system is just one part of a larger project. Our goal is to reduce and offset the energy consumption of our all-electric suburban home, so that we will generate our own electricity during nine months of the year.

We have already reduced our consumption by a quarter through more efficient appliances and inexpensive minor remodeling. We've done things like scrapping attic fans and inserting ridge vents instead, and replacing the tank water heater with an electric demand water heater. When the heat pump approaches the end of its life cycle, it will be replaced with a modern one that can heat and cool almost twice as efficiently. We also plan to add a solar water heater soon; the demand water heater will then just be used as a booster. When all these changes are made, a modest hybrid wind and solar-electric system should suffice to provide most of our electricity.

Wind Generator

Lots of valuable information about the African Windpower (AWP) 3.6 (and other small wind generators) can be found in *Home Power's* "Apples & Oranges" article by

Mick Sagrillo in *HP90.* At first I was skeptical about this machine, because according to the data, it seemed to generate little energy for its comparatively large rotor size of 3.6 meters diameter (11.8 feet). But I valued Mick's recommendation, and read about independent monitoring by Mike Klemen on the AWEA e-mail list server (see Access). This seemed to support Mick's impression that the numbers for the AWP 3.6 are realistic, maybe even a bit pessimistic, whereas some competitors use optimistic estimates.

The AWP 3.6 is available with a special, grid-tie voltage controller that shows its operation status with an LED "traffic light." The controller not only rectifies the generated wild AC into DC that the inverter can digest, but also protects the inverter by diverting surplus energy to an industrial-grade load resistor in the event of a utility outage. The Windy Boy 1800U inverter accepts a maximum input voltage of 400 VDC. When the DC input voltage reaches levels around 350 volts (yellow LED lit), a PWM circuit diverts some energy to the dump load to control voltage. A second stage, backup circuit comes into play if voltages exceed 390 volts. This "crowbar" (latching) circuit activates and connects the wind generator directly to the load resistor (red LED lit).

Although that load resistor is optional, some type of emergency load is necessary, since the generator can produce voltages high enough to damage the Windy Boy if allowed to run unloaded. Under normal operating conditions, almost all electricity is fed into the grid (green LED lit). So the load resistor has strictly a protective function—more about that later. The controller's circuit board is mounted on its own massive heat sink; the case itself is used for cooling and does not need ventilation openings. The board can be flipped over for easier wiring. Many knockouts on all four sides give flexibility when space is limited, as in my case.

The turbine's control box has two switches. The "brake" switch activates the electric brake by shorting the three alternator phases. High currents induced in the alternator will then slow down the rotor and only allow it to spin very slowly. But beware. The brake will likely not stop the rotor in high winds. It is rather intended to prevent a stopped turbine from starting up, says the manual. The wind generator is designed to protect itself in high winds through its gravity furling mechanism—just leave it alone.

Stopping the turbine seems to work better when the "crowbar" switch is on. That switch hardwires the turbine to the resistance load. It

Wind System Tech Specs

System Overview

System type: Grid-tied, batteryless wind
Location: Denison, Texas
Wind resource: 10.8 mph (4.8 m/s) annual average at 30 feet
Production: 210 AC KWH per month average (projected)
Percentage of utility electricity offset: 33 percent average (5 percent in summer, 75 percent in spring)

Wind Turbine

Turbine: African Wind Power AWP 3.6, 110 V
Rotor diameter: 3.6 m (11.8 feet)
Average rated KWH per month for battery charging turbine: 210 at 12 mph (5.4 m/s)
Peak KW output and wind speed (grid-tied): 1,580 W at 25 mph (11 m/s)
Wind turbine controller: AWP, Clamp 1
Tower: 79 foot (24 m) Rohn, guyed lattice

Balance of System

Inverter: SMA Windy Boy 1800U, maximum 400 VDC input, 120 VAC nominal output
System performance metering: AC KWH meter and integrated inverter LCD display

The Geislers' RE-powered home, AWP 3.6 wind generator, and recently added PV system.

Photo by Jim Waldon, Windmill Photography

Adding PV

A solar-electric system was started before but finished after the AWP/Windy Boy system. I ordered an SMA 700 watt batteryless inverter in March 2003, and mounted my PVs in anticipation. Working on the roof can get uncomfortably hot later in the spring. I finally received the inverter—which had been announced for June—in mid-December. This new addition to the Sunny Boy line is currently in full production and ready to ship. So the solar-electric portion of the system is complete at last and is extremely simple. The total cost of the PV system was about US$6,000.

Eight Siemens SM110 modules were wired in series using the modules' weathertight MC connectors. The DC wire run between the PVs and the inverter is 50 feet (15 m) long, and uses #10 (5 mm^2) CU wire. The resulting power losses are negligible because this is a high-voltage array. I chose the Sunny Boy 700U because it is user-configurable for three array voltage ranges or DC power inputs. One advantage of this is that it allows a given system to start small and add modules as finances allow. In my case, the Sunny Boy 700U was the best matched inverter for my array's 880 watt peak power rating under standard conditions.

Another consideration was the window in which the inverter can perform maximum power point tracking (MPPT). The SB700U tracks PV voltage from 125 volts minimum to 250 volts maximum in the configuration I chose. The inverter can accept 1,000 watts of DC input power in this configuration.

also serves as a reset if the crowbar circuit has been activated (red LED lit). An accidentally opened DC disconnect switch could let the turbine run unloaded, so instead of installing a DC disconnect switch for the inverter, I just switch "crowbar" and "brake" on. That should short the phases of the turbine and channel all electricity to the resistance load, which will normally stop it.

Inverter

SMA's Sunny Boy line of photovoltaic inverters has an excellent reputation for reliability as well as efficiency. They have won several test comparisons both in the U.S. and abroad. The Windy Boy inverter used by AWP is in fact a reprogrammed Sunny Boy 1800U. The software modification affects the maximum power point tracking (MPPT) algorithm. It causes the AC output power to be proportional to the DC input voltage. The MPPT algorithm lets the alternator work more efficiently than when charging batteries, because the load gets better adapted to the alternator's power curve. Net output increases appreciably—the AWP distributor claims a 50 percent overall gain compared to running the turbine in a battery charging system.

The physical structure of the inverter remains unaltered. With its UL 1741 listing, the inverter is regarded as precertified by our utility. It basically means that there is no special certification fee of US$200 to pay. Great! The inverter comes with an LCD display that updates vital information every five seconds, among them instantaneous power output, accumulated energy output, input voltage, and error messages. It also has three status LEDs. Documentation is extensive.

Electrical Setup

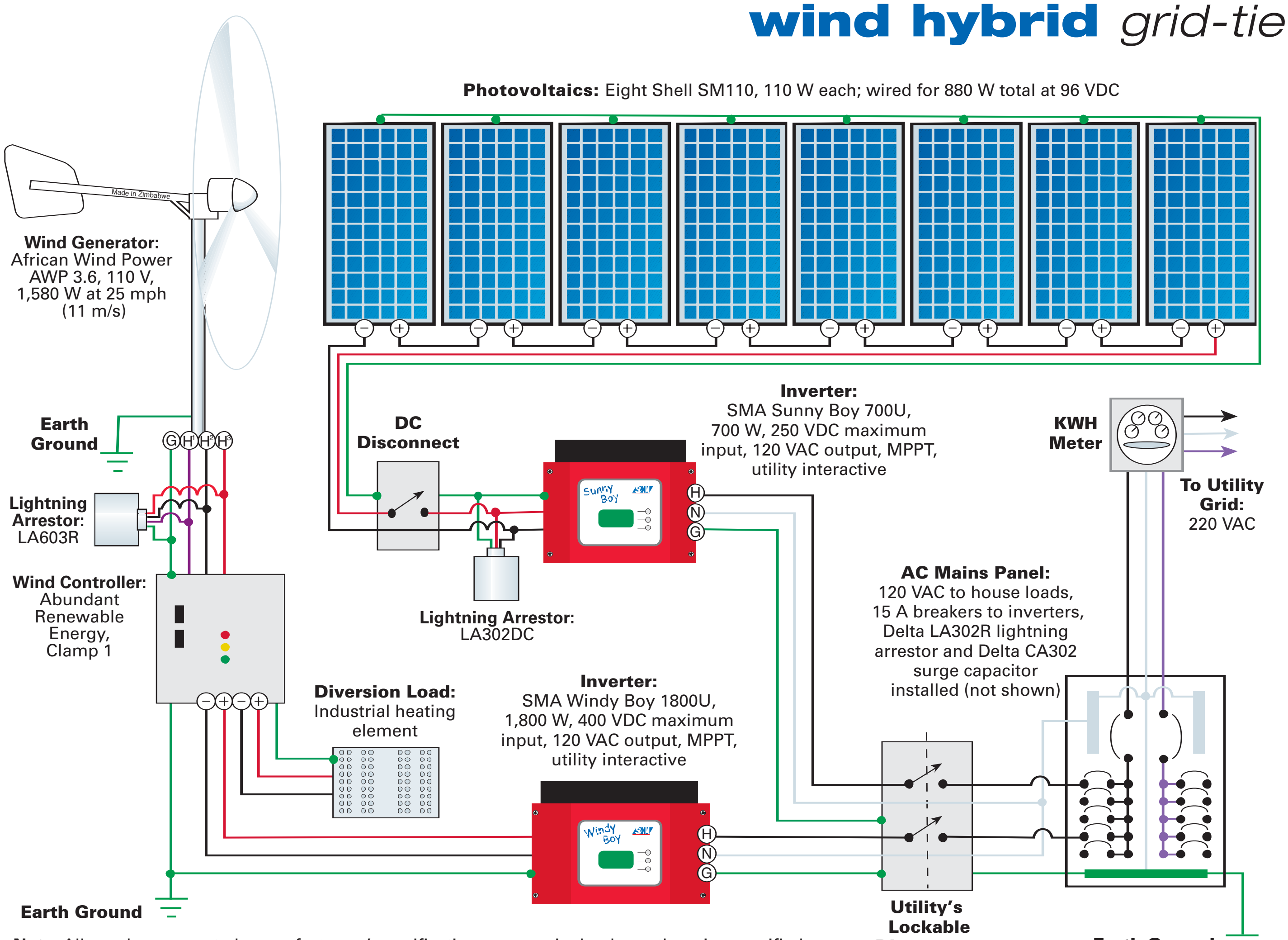
I started with the electrical installation. Besides the components mentioned above, utilities usually require a lockable disconnect switch. All generating sources must be able to be disconnected from the grid with one single switch that can be accessed outside the house and locked in the "off" position. I am not sure whether such a switch has ever been used by any lineworker.

Drilling holes through brick walls is no fun, so I looked for a more elegant way. Although my idea is probably not new, pulling a four-conductor cable through the conduit between the main breaker panel and the utility meter on the outside wall was a fast and clean solution. The conduit in my house could easily accept another cable besides the two hot phases and the ground. With the cable now ending in the main breaker box and the meter box, respectively, I just connected the switch with a short piece of conduit to the meter box and pulled the cable through. Since the wind generator and solar-electric array needed to be switched off simultaneously, I employed a two-pole, 30 amp disconnect switch.

Inverter Output & Input

Inside the main breaker panel, I connected the wire from the disconnect to the dedicated breaker for the Windy Boy. The wire to the disconnect was fed into the inverter as L (Line). The inverter also needed one connection to N (Neutral) and one connection to PE (Protective Earth, or ground) on the AC output side. The 15 amp circuit breaker serves as the inside AC disconnect switch for the inverter, and there is also the utility disconnect outside.

The AWP control box was easily connected between the wind generator and inverter. Eight obvious connections had to be made, three to the 3-phase alternator, two to the load resistor, two to the inverter DC input, and one to ground. I crimped and soldered all electrical connections because I think the additional time spent for good connections may protect against future trouble.



Note: All numbers are rated, manufacturers' specifications, or nominal unless otherwise specified.

Lightning Protection & Wire Run

With a properly grounded and protected tower—bonded, 10 foot (3 m) ground rods at the base and guy anchors, and a lightning arrestor—the greatest danger to electronic devices comes from surges within the grid. So I connected one Delta LA603R across the three alternator phases in the control box, one Delta LA302R lightning arrestor and one Delta CA302 surge capacitor across the two grid phases in the main breaker panel, and one additional Delta LA302DC lightning arrestor for the PV panels.

For the 320 foot (98 m) wire run from the control box to the tower and up to the wind turbine, I used #6 (13 mm^2) direct burial cable with three conductors and ground. Near the junction box at the tower base and at the house entrance, the cable is run for about 12 feet (3.6 m) in 1 inch flexible conduit. A table with recommended wire sizes for different run lengths is part of the owner's manual for the AWP 3.6. House and tower ground rods are electrically connected.

No Slip Rings

The AWP 3.6 has no slip ring assembly, the component in most small wind generators that transfers the electricity from the rotating wind generator head to transmission cables going down the fixed tower. Instead, the AWP allows the transmission wires to twist up if the turbine yaws more in one direction than another. (Future versions may have slip rings, due to popular demand.)

Although this seems primitive, it may actually be a long-term reliability advantage. Several experts confirm that slip rings and brushes are a problem zone. Looking at my previous wind turbine, I realized that after 15 years of exposure to the elements, the plastic had become so brittle that the brush holders were literally crumbling apart. So I am inclined to believe that in the long run, three solid metal lugs may be a better investment than a set of cheap slip rings. Time will tell.

As the wind turbine yaws, it will twist its wires. The heavy 3/6 cable that runs up the guyed lattice tower is very stiff and cannot be twisted easily, so I used three, more flexible #8 (8 mm^2) wires that connect to the turbine through the tower top adaptor. I plan to untwist the wires when I do my twice-a-year maintenance.

Mechanical Setup

While bolting the wind generator together, I could not fail to see that its designer Hugh Piggott knew what he was doing. Although the design looks rough, almost crude at first sight, a second look reveals that it is ingeniously simple, using very few parts, which can all be produced with simple tools. I bet any person with a bit of technical talent will be able to assemble this machine without even

Balance of systems equipment—(clockwise from top right) Sunny Boy 700U inverter, Windy Boy 1800U inverter, Abundant Renewable Energy wind controller, diversion load, and AC mains panel.

looking at the manual—the parts let you know how to mount them. (Just remember that the curved sides of the blades face the tail.)

I had my 72 foot (22 m) guyed lattice tower already in place from a previous wind generator that broke down. I used the gin pole with three pulleys for pulling up the tower adaptor. My adaptor was welded at the local machine shop for US$219, with another US$102 for hot-dip galvanizing. After bolting on the tower adaptor, I set the gin pole higher and bolted it onto the adaptor with 1/2 inch (13 mm) U-bolts. That gave me the necessary height to lift the wind turbine.

I used my truck for pulling on 270 feet (82 m) of 3/16 inch (5 mm) aircraft cable. The way that I arranged the pulleys reduced the required force to half while it increased the cable travel by a factor of two. That allowed for quick and precise lifting with just three people—one in the truck, one at the tag line (rope to control swing), and one giving signals. Nobody needed to be on or even near the tower during lifting. If you try such an operation yourself, make sure you use industrial grade pulleys and cable or rope that exactly matches the roller size. My cable was too thin, jumped off the roller when the turbine reached the very top and jammed between the roller and its frame. We still got it bolted on, but had to fight much more than necessary. Hub height is at 79 feet (24 m).

Most people will use a different type of tower, anyway, so I listed costs for an 85 foot (26 m) tilt-up tower in the table. Tower kits for the AWP 3.6 are available from the American distributor, Abundant Renewable Energy, and come in heights ranging from 43 to 127 feet (13–39 m). You will need at least 5 cubic yards of concrete for the guy anchors and base.

Utility Issues

Dealing with the utilities has become easier since transmission companies were separated from the generators of electricity. In my case, the local grid is maintained by Oncor, whereas I can buy my electricity from TXU or another provider. The transmission company had no reason to put obstacles in my way because I am not going to hurt their business. They get their money either way. In fact, they employ special consultants for distributed generation who handle cases like mine. These people would lose their jobs if distributed generators did not exist. So our relationship has been quite friendly.

The interconnection process consisted of two relatively short documents—an application for distributed generation and the agreement for interconnection. The application was a two-page document and lists my address; technical information about the inverters, like voltage and current ratings, power factor, and UL file number; and a one-line diagram of the installation. The one-line diagram is a simple system schematic where all elements in the generation chain from the wind generator to the utility transformer are each symbolized and connected with a single line.

The agreement for interconnection apparently applies to all kinds of generators (one size fits all...) and therefore was more elaborate than necessary for my small turbine. I regarded the agreement as fair because the company and I both had to agree to the same terms regarding liability, indemnification, etc.

Helpful advice can be found in Paul Gipe's book, *Wind Power for Home and Business.* Do not expect any special treatment from the utility. You will either accept their terms and conditions or stay out. At least they must acknowledge your right to interconnection (PURPA). I was offered three different options: a) annual net metering with a single meter, but no payment for excess, b) payment for net production with two ratcheted meters for net production and net consumption, or c) payment for all production, metering all consumption and all production.

Since I will probably never generate more electricity than I use, I accepted the first option. This was the least bureaucratic and work intensive. I did not argue with the 800 pound gorilla that they did not have any legal right to dictate those options unilaterally. But with an annual instead of a monthly billing period, even a short-term overproduction will be fully paid for.

Operation

The AWP 3.6 operates very quietly, getting about as loud as when you hold a sea shell up to your ear. It will start up as soon as leaves in the trees are moving. Just don't expect more than a few watts output then—there is little energy in these winds. It is still pretty to watch, though. So far I have observed a maximum of 1,580 watts instantaneous output at

Geisler Wind Costs

Wind Turbine & Inverter	Cost (US$)
Windy Boy 1800U SBD inverter	$2,260.00
AWP 3.6 turbine, 110 V	2,250.00
Voltage clamp	600.00
Load resistor	240.00
Total Turbine & Inverter	$5,350.00
Tower, Hardware, & Tools	
AWP tower kit w/ pipe, 85 ft.	$3,100.00
3 Cables, #6 direct burial, 320 ft.	252.80
Concrete, 5 cubic yards	247.50
Backhoe work	150.00
Ditch Witch (rented)	125.00
Delta LA603 lightning arrestor	85.64
Delta CA302 R surge capacitor	57.43
Delta LA302 R lightning arrestor	44.95
13 Rebar, 1/2 in. x 20 ft.	38.35
Fused disconnect	34.95
Junction box	19.94
8 Wire lugs	16.80
Conduit, 1 in., 12 ft.	10.80
4 Conduit connectors, 1/2 in.	9.78
4 Cables, #8, 4 ft.	4.14
Circuit breaker, 15 A	3.56
Conduit, 1/2 in., 6 ft.	2.76
2 Conduit connectors, 1 in.	2.39
Total Other	$4,206.79
Grand Total	$9,556.79

the inverter. Considering inverter efficiency of 93 percent and 2 percent transmission losses, this indicates a peak output of more than 1,700 watts, and easily confirms the turbine manufacturer's output claims for batteryless, grid-tie systems.

The turbine generated a record output of 15 KWH during one day and night with steady high winds around 25 mph (11 m/s), which approaches the range that can be reasonably expected, according to the power curves. I have routinely observed energy outputs of 10 KWH per day in winter for five consecutive days. My AWP 3.6 keeps generating between 800 watts and 1,000 watts even while furling all the way. I like that because it would be disappointing to see it shut down exactly when the resource is best.

One time after we installed it, my turbine operated through a thunderstorm with 3/4 inch (19 mm) hailstones. Although I feared the worst, I found no damage except two tiny paint chips on the leading edges of two of the blades. Those blades are very strong for their weight. The utility grid also broke down for a few seconds, and the inverter accordingly disconnected. During that time, the DC voltage rose to 390 volts, but the energy was safely transferred to the dump load. When the grid stabilized, the system reactivated itself.

Efficient & Hypnotic

The grid-intertied AWP 3.6 does not provide emergency electricity, but generates about 50 percent more than the battery charging version, while using less space in the power room and saving battery maintenance and costs. The complete system impressed me with its sturdiness and quality, except for the paint job on the alternator. It is straightforward to install, and requires no active human intervention.

The quietly and slowly turning wind generator looks and feels more like a natural addition to our residence than like a high-tech artifact. Just watching it carries its own reward for me—it's like staring into a fire. Amazing...

Access

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Robert Preus, Abundant Renewable Energy, 22700 NE Mountain Top Rd., Newberg, OR 97132 • 503-538-8298 • Fax: 503-538-8782 • robert@abundantre.com • www.abundantre.com • U.S. distributor for AWP

"Apples & Oranges," by Mick Sagrillo in *HP90* • Excellent overview and comparison of wind generators

"Small Wind Electric Systems—A U.S. Consumer's Guide" • www.eren.doe.gov

Wind Power for Home and Business , Paul Gipe, 1993, Paperback, 432 pages, ISBN 0-930031-64-4, US$35 from Chelsea Green Publishing Company, PO Box 428, White River Junction, VT 05001 • 800-639-4099 or 802-295-6300 • Fax: 802-295-6444 • info@chelseagreen.com • www.chelseagreen.com • A truly valuable book about small wind systems

American Wind Energy Association's discussion group • http://groups.yahoo.com/group/awea-wind-home • The best resource if you have technical questions or problems

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