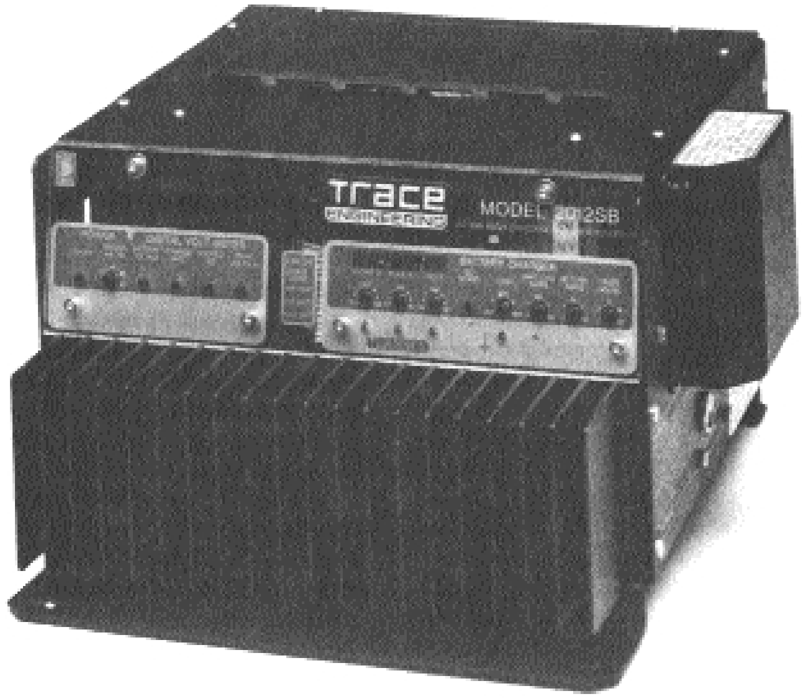
How an inverter fits into your solar electric system



Inverters change a battery's direct current to alternating current so you can use the electricity with everyday household appliances.

By Joel Davidson

Early on in PV history, the use of inverters was downplayed and most people used direct current. PV systems were costly and small-sized. Inverters consume power, and when PV was two to three times its present cost, that power was too expensive to waste.

PV pioneers were willing to put up with DC systems. They either hunted up DC appliances, modified existing AC appliances, made gadgets from scratch or did without. It was a time of DC lights, fans and radios salvaged from cars and trucks. Much time was spent scrounging through catalogs and shops looking for military surplus DC motors and other goodies. Some very creative solutions resulted and a few DC PV businesses flourished for a time.

Even today the DC tradition has been passed on as part of the credo of energy conservation. A guideline for designing small PV systems is, if you can power something directly with DC, do it.

One idea that has grown less popular through changes in technology is record turntable modification. Since better belt-driven turntables use DC motors, it seemed logical to bypass the input transformer and go straight to the motor with 12 volts or whatever the DC requirement was.

For the non-technical: If you trace the power cord from the plug into some devices, the input transformer is the first thing you may find. The purpose of these coils with a magnet is to take the 120-volt AC utility power coming into the transformer primary coil and return reduced voltage from the secondary coil. That reduced voltage is then rectified to DC for use in the low-voltage DC circuitry of the solid-state electronics found in most everything nowadays. For the PV pioneer, much time was spent discussing which devices could be used directly in the DC mode. A voltmeter put across the secondary windings of the input transformer would often tell the story.

Reading the voltage and making modifications meant opening up the device. Electrical hazard warnings and threats of voided warranties notwithstanding, it was strange to open up a case which says "No Serviceable Parts Inside" or "To Be Opened Only By A Qualified Service Technician" and find 12 volts DC just waiting to be powered by PV.

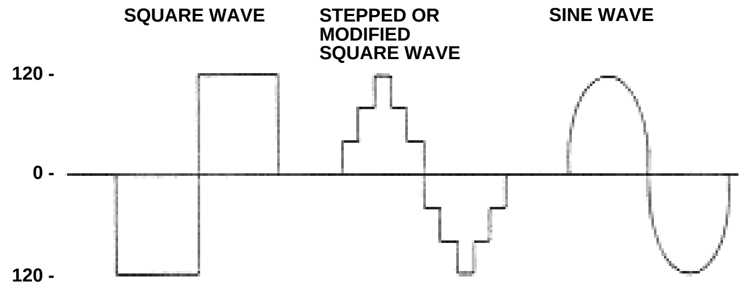
Amateur radio operators and computer tinkerers were already familiar with these exploratory operations. They knew that most solid-state electronics were low voltage, usually 12 volts or less. Thus, ham radios and computers were among the first high tech equipment to be PV-powered.

In the early 1980s two trends evolved. Tracking the growth of the recreational vehicle industry, all kinds of DC appliances began to appear. RVers like gadgets, and the manufacturers were accommodating. In one Automotive catalog, five models of DC vacuum cleaners were listed. I tried them all. To my disappointment, they were hardly more than toys (though some cost more than small home uprights). They worked, but were designed for small tasks, not cleaning a house in the country where dirt is always getting tracked in.

There are other examples of DC devices that couldn't quite do the job. There were blenders that couldn't crush ice, soldering irons that couldn't solder large wire, drills that broke after a few hours, bug zappers that missed the big ones. Needless to say, there was room for improvement, and things have improved. Nowadays, we can find better DC appliances though at a premium price.

Fortunately, another trend was occurring. People were beginning to experiment with inverters. Users were willing to sacrifice the AC appliances they had stored away and to experiment with early square-wave inverters. Some people used old-style motor inverters and got satisfactory service but. low efficiency. Some even bought expensive sine-wave inverters costing as much as their entire PV system.

The more technical PV users at that time were building their own. From early designs and testing came a new generation of inverters which was to change the nature of PV use and make the old DC bias obsolete.



The wave forms of various inverters from the most primitive simple square wave to pure sine wave. For most applications, the stepped wave will work well and reduce inverter costs.

What is an inverter?

An inverter is a device that changes direct current to alternating current. (Converters, sometimes called rectifiers, change AC to DC). For our purposes, we are speaking of 12-, 24-, or 48-volt DC power inverted to 120 or 240 volts AC. (See Figure 1)

Don't let other approximate AC voltages confuse you. You will hear 110 volts or 115 volts or even 117 volts. The range is 110 to 120. However, actual readings maybe greater or less. There are two conventions, 110 and 120. Old timers use 110, but the catalogs typically spec electrical equipment at 120 and 240 for utility voltage. Unless your equipment specifically requires something other than utility power, 220, 230, and 240 volts are also interchangeable. The simple test is if you can plug it into grid power, call it what you will - it's 120 or 240 volts AC.

Europe has different voltages, generally 230 volts 50 Hertz (named in honor of an early experimenter in electricity). The difference is the frequency at which the current alternates (thus, alternating current or AC. In the U.S. we use AC at 60 cycles per seconds or 60 Hz.

While the purist may want to operate his PV-powered home entirely on DC, there are some limitations. Besides limited availability of appliances, larger wire is required to carry the same power load. For example, a 200 watt load at 12 volts needs wire large enough to carry 16.6 amperes, whereas the same load at 120 volts is only 1.66 amperes.

Too often in PV discussions we hear a lot about inverter efficiency losses and very little about the cost of large wire used for comparable DC loads. We won't mention wire loss inefficiencies because of undersized conductors. That kind of penny-pinching is, in fact, just throwing good money away. Sometimes those losses and costs can be as much as the difference in the cost of using an inverter. Factored into cost somehow should be the time spent making do with DC, but that is not often the case.

Inverters come in all sizes, shapes and price ranges offering a vast array of options. Some inverters produce the simple square wave suitable for most loads. While there is reason for concern about the quality of square-wave AC, it will do the job. Surprisingly, most computers will operate on square wave. Some computers have power conditioning equipment built into their power supplies which allows for almost any quality of electricity. This is done because grid power is so variable. I powered my Apple H Plus and two disk drives and Epson printer with a very simple 550-watt square-wave inverter satisfactorily.

Recently, my office was moved to the front of the building which is serviced by the utility company, while my PV system remained connected to the old office. One morning I turned on my computer and a surge or spike zapped the computer power supply resulting in costly repairs. When I got the computer back from the shop, I ran a 120 volt AC line from my old PV system to the front office, specifically dedicated for my computer. Needless to say, I am relieved to be back on smooth and reliable PV power again. (When I'm on the road, I also avoid unregulated grid power from ruining my computer. A second battery in my car and a 300watt inverter are my portable office power supply and Uninterruptible Power System. If I have to stay on location a few days, a portable PV array provides all the power my office on the road needs.)

More costly inverters put out a modified, or stepped, square wave which more closely matches grid power. Some test equipment needs the exact type of power produced by the utility company (60-cycle reference sine wave) to operate. In that case, a costly sine-wave inverter is necessary. The early sine-wave inverters were actually square-wave devices with ferroresistant transformers to smooth out the flip-flop square wave. Thus, efficiency was sacrificed in the transformer to produce pure sine-wave inversion.

Now there is a new generation of inverters: relatively lower cost, very high-efficiency digital sine-wave inverters. They can power anything just like grid power-and they are changing the way PV will be used.

So far we have been discussing solid-state, or electronic inverters. An old standby is the rotary or motor inverter. This device is a motor which drives an alternator. The DC power runs the motor. A common shaft ties the motor and alternator together, and the output of the alternator is sine-wave AC.

If rotary inverters put out a nice sine wave, why aren't they used more often in PV systems? The simple fact is that they are not very efficient. At less than 65% efficiency, and as low as 30% efficiency with loads 20% of the rated output, rotary inverters are not particularly suited to PV. This is primarily due to the amount of energy required to move the motor and alternator. PV electricity is too precious to waste on spinning parts. But for the occasional, short-duration sine-wave load, a rotary inverter may be just the thing.

Also, the rotary, inverter output voltage varies in direct proportion to the DC input voltage. This means that as the battery discharges, the output voltage falls with it. Even though the output is a sine wave, you can see the voltages varying from as low as 90 volts to upward of 140 volts AC.

One nice thing about rotary inverters is that they can really take a beating. They handle motor-starting well. I know of cases where rotary inverters were used until they began to heat and smoke. After cooling off a while, they were called back into service and performed without any problem. You can't beat that for durability.

On the other hand, a good solid-state inverter should have enough protective circuitry to do the same. Of course, it shouldn't have smoke coming out of it, but if it can't take motor surges and occasional overloading, then it is under- designed.

I mention under-design because inevitably an inverter is called on to handle loads beyond its rated capacity. People have a tendency to pinch pennies when buying an inverter, opting for the smallest size they can get away with. Then they push it to the maximum. Inverter manufactures know this. For that reason, wise inverter builders factor in extra capacity to insure long life. But don't rely on the "fudge factor." Keep the use of your inverter within its factory ratings.

Solid-state inverters may also have an automatic demand on/off. This means that you can turn the inverter on and leave it on, using relatively, little power, until a load comes on. When it senses a load, the needed power is applied. Without a load, it waits. In the on and no-load state your inverter should use little power. If your inverter does not have, a low no-load mode, be sure to turn it off when not in use. Do not waste your PV power.

What can you power with an inverter? Basically anything that operates from the grid can be operated with the modem solid-state inverter. Resistive loads like coffee makers, toasters, and hair dryers will operate with no problem, as well as incandescent lights. Fluorescents may not work well if your inverter does not interface properly with the fluorescent ballasts.

Some induction or brushless AC motors have very high starting surge requirements. Well pumps, garbage disposals, dishwashers, refrigerators, air conditioners, and washing machines all have high starting surges. These surge requirements can be as much as five times the normal operating power requirement. Thus, the 300 watt motor load of a refrigerator may not even start if your inverter is rated less than 1500 watts.

Some motors do not work well with some inverters. Why is this? Is it the fault of the motor or the inverter? The answer is both. Motors are made as cheaply as possible nowadays. Most manufacturers leave out what is commonly called the motor-run capacitor. The job of this capacitor is to smooth out the interaction between the load (motor) and the power source. Grid power with its pure sine wave does not create as much bad feedback (inductive reactance) with such loads, but some inverters do.

If you find that motors are not running up to normal speed with your inverter, try putting a 3- or 4-microfarad 400-volt electrolytic capacitor across the motor windings. Such a capacitor maybe purchased for under $10 at most motor stores. Be sure to note polarity when installing the capacitor. If you don't know what you are doing, ask questions. Also, be sure to put the capacitor on the motor side of the switch so that it does not load your inverter when the motor is off. If you use an inverter designed for reactive loads, this should not be a problem.

Selecting an inverter

There are a few basic guidelines to use in selecting an inverter for your PV system. First, you need to know your power requirements. We always come back to this. The power requirements identify the loads and how long they will be used. Your power requirements list will give you an idea on what will be operating on AC and what AC loads will be operating at the same time. The inverter must be able to handle the combined AC loads which will be operated simultaneously. In fact, the inverter must be able to handle the surge of these loads, too.

Note the type of loads to be powered by the inverter. Are they motor loads with high starting surges? Is complex electronic equipment to be powered? How about kitchen loads? Will you be running the garbage disposal and dishwasher at the same time? If so, don't forget to include the well pump as you will be using water, too. And finally, don't forget the refrigerator. It can come on while all these other loads are running.

Total your automatic loads and surges. Then add up demand loads, such as dishwasher and washing machine, and your convenience loads, such as blenders and toasters, separately and in possible combinations of simultaneous operation. After you have done that, you may find that you will have to monitor your combined loads to keep the size and cost of your inverter to within reason.

There are a couple of other reasons to look at your power requirements when considering an inverter. When you size your system and allocate your budget, the inverter should be considered in your first purchase. Although inverters come hi a variety of sizes, it is false economy to buy a small inverter you will soon outgrow. Buy the inverter that will suit your future needs now.

There's a good reason for up-sizing. When starting out, you may have lots of construction or remodeling work to do. A bigger inverter will help you through this period with ease. It sure is nice to have a quiet inverter instead of a noisy generator when you are doing carpentry. And besides, what if your generator breaks down? Then you are faced with a repair job before you can do the construction work.

Once you are settled in, the over-capacity of a larger inverter bought for construction purposes still has merit. Operating inverters at or near capacity may give high efficiency, but also may lead to shortened inverter life. Some, over-capacity is good insurance.

On the other hand, a small inverter may be all you can afford, especially if you are installing PV in stages. Be sure to plan each ‘additional part of your wiring though, or you will have imbalanced circuits. If you use a couple of smaller inverters for your loads, you have insurance in the form of redundancy. If one inverter should fail, you’ll still have the other one. However, if the bigger one fails, will the smaller one adequately operate important loads?

This brings us to cascading inverters. While no inverters can be paralleled on the same circuit without one burning up the other, some inverters can be tandemed for increased capacity.

Heart Interface was the first company to address the needs of the inverter market and was the most popular inverter for remote home use. Their first inverters reached peak efficiency at a very low load level, one or two lights. Their surge capabilities were good, and they ran motors efficiently. Among their deficiencies were reliability, changing internal adjustment and slow warranty repair. Many of these questions were met by Heart Interface. In 1985, Heart Interface began marketing inverters which could be tandemed for bigger loads.They did this to improve efficiency and to eliminate the costly 5000-watt inverter. Unless your loads are always big, a 5000-watt inverter is not such a good idea. It just doesn't't~t make sense to use a 5000-watt inverter to power a 100-watt load. On the other hand, if you need an inverter to handle a 5”-watt, you must use one. Cascading or tandem inverters get around this mix. By stacking up to four 2500watt inverters, you can handle big loads. The stack will be called on only if needed.

Should you ever have a problem with one of your cascading inverters, you will still have the others. Not a bad idea. For planning purposes, cascading inverters make sense, too. Let’s say you are just getting started, and want to power your home with PV. Your eventual full complement of loads will be large. However, in the beginning you may be operating on a limited budget or requiring a- limited amount of power. By using the first of a cascading inverter, you can squeeze by. Later you can add on as needed.

A word of warning: Never put two AC inputs on the same circuit or something will burn. That means never feed your generator or grid power into a circuit being powered by an inverter at the same time. Wire your home so that this can never happen. Never feed generator or inverter power into the utility grid without the power company’s permission. In the first place, it is illegal. More importantly, it endangers power line workers.

Buying an inverter

When you buy an inverter, get one that can be repaired. And hope that the company that manufactured it and the person who sold it to you will stay in business. Buying close-out inverters’ is unwise. Where will you get technical support when you need it?

It is always a good idea to ask your seller if you can call for technical information after the inverter is in place. If you have hired someone to install your system, get a service contract that includes replacement. This may cost extra but it may be worth it because should the inverter fail you won’t be without power.

All inverters must be tested when installed. Some may have to be adjusted for the specific installation. Be sure to ask “What if .. ?” If you don’t like the answer, shop elsewhere. A reputable inverter sales outlet should satisfy your every need.

Probably the most popular inverter today is the Trace. The Trace Engineering Co. is a spin-off of Heart, and the company solved many of the problems in the Heart units. They boast a two-year warranty and so far there have been few warranty repairs. All units are delivered by UPS, meaning cheaper warranty repair and delivery price. These units have no adjustments to fail. The inverter is self-monitoring and modifies its internal workings and corresponding parts specifications as the temperature changes. These inverters have very high surge capabilities and will run large loads for the short periods of time that are needed in a remote site home. The basic 2000-watt 12 volt model or the 2500-watt 24 volt model will run the right 1/3 HP deep well pump and the right washing machine at the same time. Turn on voltage, turn off voltage, and charging ampere are all user selectable. The best part of all is that they are much cheaper than any of the competition.

Disadvantages

With all this talk about the wonders of inverters and their benefits, what are the disadvantages? We will not even consider poor quality, low-efficiency inverters. Of the good inverters, there will inevitably be problems, usually in the first few month, as they “burn-in” or get adjusted to regular use. Other problems occur because of bad installation, undersized DC input wires, rough handling, and overloading.

A disadvantage already mentioned is your reliance on the inverter to power all your loads. Should your inverter fail even if fully warranted and all the repairs or replacement are cost-free, you will be without all or some of your load-carrying capacity. If everything electrical is AC, then you are out of luck -and power. Let?s hope. you at least planned in DC emergency fights and water to carry you through any waiting periods for parts and repairs.

A less important disadvantage of inverters is efficiency. This has become, a secondary consideration since the advent of 90% plus efficiency field effect transistor (FET) inverter technology. But it still should be considered. If your system is small and your budget limited, perhaps an inverter is not for you. A 10% loss can be costly if you are operating on a shoestring.

Conversely, an inverter makes wiring a lot cheaper. You can use readily available low-cost standard wiring and hardware. Switches and breakers and all the other goodies used in AC homes are relatively inexpensive. The savings on the wiring along with the convenience and savings in using standard appliances makes shoestring DC almost a thing of the past.

The PV/grid connection

It is possible to install a medium to large-sized residential PV array and remain hooked up to the utility power grid. The advantage of this type of installation is that the battery storage system is eliminated. When the sun is not producing enough power to run the home's electrical appliances, or the peak load is greater than production, the grid-connect PV home gets its power from the utility company. When PV production exceeds consumption, the home is credited or actually paid for the power it produces and puts into the utility grid.

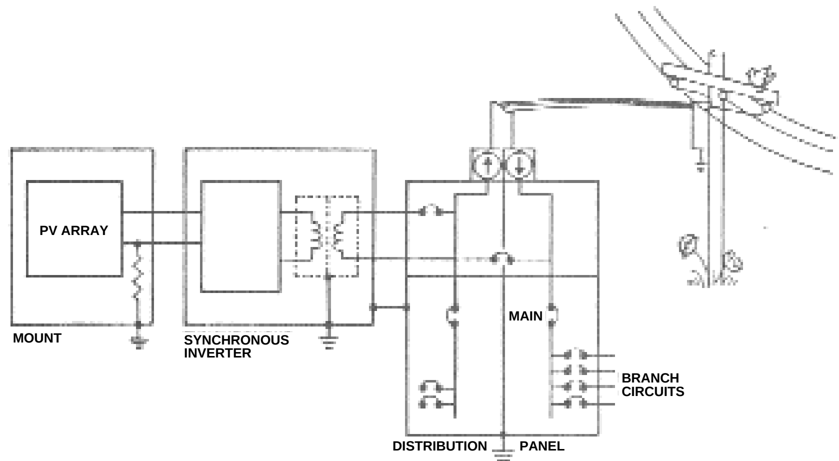
Although there are a few thousand grid-connect wind power homes, there are far fewer grid-connect PV homes. The two main reasons for this are economics and a lack of marketing. It has been difficult to present an economic argument for PV/grid homes because of their cost compared to buying a monthly electric bill. But like so many things that are not "cost-effective," PV/grid homes could have been marketed to the affluent for other than economic reasons. Unfortunately, they were not. On the other hand, Windworks, maker of the Gemini Synchronous Inverter, did an excellent job building a reliable grid-connect inverter for wind systems and did a good job selling it. In fact, they looked so good that a Wisconsin utility company bought the company.

In addition, Windworks was able to get parity pricing for their customers. They did all the system engineering with the approval of the utilities, and, in exchange, customers usually got one meter installed, which ran backwards when the system produced power. Nowadays we generally see two meters on these systems—one for buying power and one for selling. Parity pricing for alternative power systems is pretty much a thing of the past.

So the development of grid-interconnect windchargers proceeded smoothly with intertie equipment costing about as much as a battery bank. Parity pricing and the elimination of battery maintenance were important selling points.

the array while monitoring the power output. Therefore, the array's highest wattage regardless of a standardized voltage is what the electric meter sees.

Do not confuse power tracking with physically tracking the sun. Power tracking is electronic peak power-seeking circuitry built into the power-conditioning equipment. In some DC PV water pumping systems, peak power tracking is used to match array output to optimum motor operation.



The synchronous inverter interconnects the solar array to the home and the utility company. At the main distribution panel, power can flow in two directions. During the day when an excess of PV power is being produced, it is sold to the utility. At night or when loads exceed PV production, power is bought by the utility.

A few Gemini inverters were also used on PV systems. Today we see wind and hydro grid-interconnect systems using a variety of inverters similar to . the Gemini.

Synchronous inverters are line-commutated, line-feeding inverters which change DC power to AC at standard line voltages and frequency. In operation, all the available DC power is converted to AC. If more power is available from the DC source than is required by the home, the excess flows into the AC grid where it is used by others. If less power is produced than is being used, the difference is provided by the AC grid.

The inverters have circuitry capable of handling unregulated DC power input. For PV arrays, where the maximum power output is not a function of a single variable, automatic tracking circuitry seeks the highest output by incrementally varying the loading of

The installation of synchronous inverters is generally beyond the scope of the average homeowner. An electrician is needed to do the job. In addition, utility company engineers will want to be involved to insure that the system is safe and producing power equal in quality to grid power.

The belief has been that when PV prices drop, more grid- interconnect systems would be installed. However, when PV modules were selling at half price (as they effectively, were when the tax credits were available), there was no rush to install these systems.

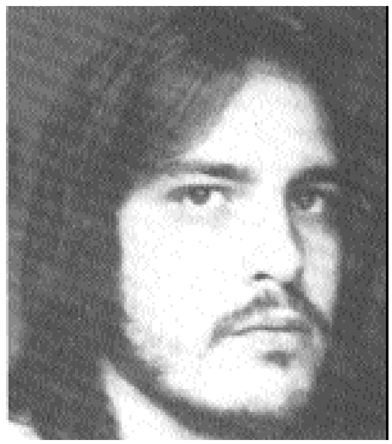
Another factor that has limited the installation of PV grid interconnect systems is that utility companies considering grid interconnect of power fields have the advantage of economy of scale. Why would someone interested in PV and able to afford grid interconnect system do so if their utility company was going to do the same thing on a larger scale at a lower price per watt? Logically, by paying your monthly electric bill, you could buy utility solar electricity and support a much grander step toward a PV society.

As it turns out, few utilities are willing to put in PV power fields. Those utilities that have, publicize their efforts out of proportion and give the impression that they are "going solar" for their customers. Thus, rate payers are discouraged from the PV/grid connection because they mistakenly think their utility company has done it for them.

But even with short-term economics against them, some true pioneers have put in PV/grid-interconnect systems. Not only did they have to convince themselves of the merit of PV, they also had to convince their utility company. Now.that a few people have made the grid interconnection, we are seeing more cooperation from the utilities. In fact, some of the most publicized grid interconnections have been those done by utilities.

Steve Strong, architect and designer, had done some excellent work on grid-interconnect homes. All have been costly, but they have paved the way for general acceptance of the concept. Steve's first grid-interconnect PV home (built in Massachusetts) cost about the same as non-PV homes in the same neighborhood. His work has been featured on the PBS series "The All New This Old House." Perhaps one of the most important impacts of his "Impact 2000" PV-powered home has been on Boston Edison, the utility that commissioned -the job, for they are now able to see that PV can work in their locale. It is also providing valuable design guidelines for other architects willing to follow in Steve's steps. Δ

(This article was reprinted with permission from Joel Davidson's book, "The New Solar Electric Home," which is available for $20.95 from aatec publications, P.O. Box 7119, Ann Arbor, MI 48107.)



A BHM Writer's Profile

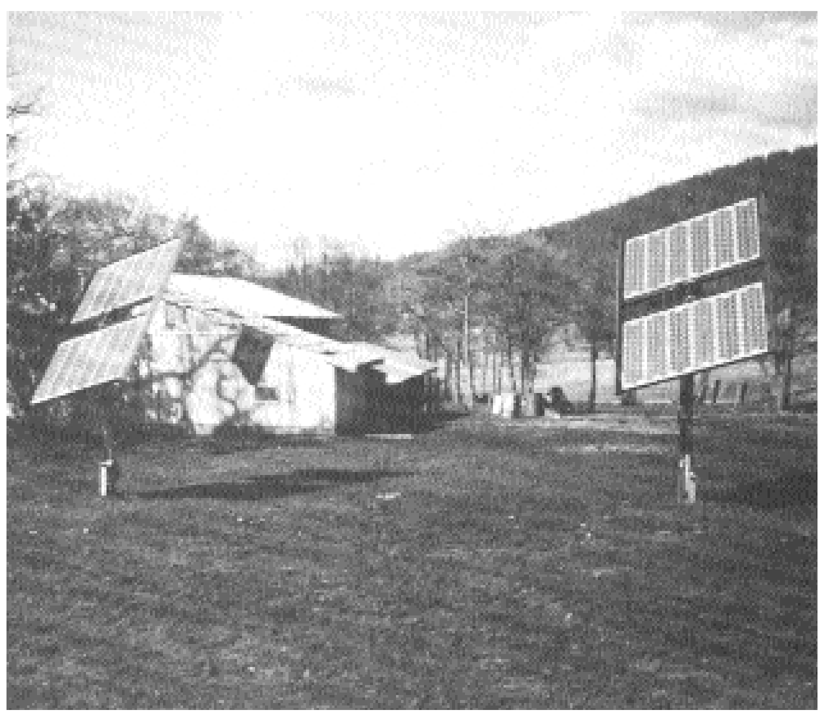
Martin P. Waterman is a rural based writer whose work has appeared in numerous publications in Canada and the United States. He also writes a syndicated gardening column and is often a lecturer at horticultural symposiums.

Mr. Waterman is also involved in agricultural research and is a recognized fruit breeder striving to develop new hardier varieties for colder climates.

A BHM Writer's Profile

Vernon Hopkins gets a kiss from his great great granddaughter, Devyn, on his 80th birthday. Vernon is a retired trapper of 40 years, and he has witched wells for the past 30 years with a success rate of about 95%.

We profiled his extraordinary life in Issue No. 2 and he subsequently became a writer for the *Backwoods Home Magazine*. Vernon brings his extensive knowledge as a naturalist and observer of the natural world to BHM.



Getting electricity from the sun