

**HIGH
VOLTAGE**

**By Michael
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**LOW
VOLTAGE**

It's refreshing to see the growing popularity of renewable energy (RE) systems—i.e., those tapping the energy of the sun, wind, and water—ranging in size, sophistication, and cost. The hardware in these systems has grown to be widely available, reliable, rugged, and warrantied, and improved in the way it interfaces with utility systems and standby generators. The owners of these systems are generally savvy about their systems and, indeed, may have been involved both in the design and installation.

I find one trend in today's RE systems somewhat alarming: an increasing dependency on 120Vac, 60-cycle output only. Or, more specifically, a decrease in the use of the dc power available directly from battery storage.

The design decision to exclude dc power usage is often rationalized on the basis of costs related to power transmission and system wiring, or siting a standby generator housing. In my opinion, in most cases, this is a mistake.

Before I launch into my 12-point argument in favor of using dc power in conjunction with ac power, let's make certain we're all working on the same page. What is ac? dc? Battery voltage? System voltage? Low vs. high voltage? What factors affect the transmission of power?

ac power

In the USA electrical power supplied by the utility and available at a standard receptacle in a house or shop is 120V, 60 Hz ac. Unabbreviated, this is electricity of 120 Volts (after Volta) potential with an alternating current at a frequency of 60 cycles (or Hz, after Hertz). Hereafter, I'll refer to this AC signal as 120Vac.

If you're under 50 years of age, you've lived with 120Vac all of your life. Most household loads, i.e., lights, refrigerator, motors, appliances, TV, stereos, tools, etc., are rated to work at 120Vac. If you've traveled widely, you know that the voltage available in

Left (Figure 1): A tall tower works both to position the wind-electric machine above surrounding trees and to expose it to the energy of higher windspeeds.

other countries varies (higher and lower than 120 Volts) as does the frequency (i.e., 50 cycles).

This standard of 120Vac is further reflected in the output of generators and inverters. A standby (or auxiliary) generator powered by a gasoline, diesel, or propane-fueled engine is often used in RE systems as a backup source of 120Vac electricity to directly power loads. An inverter is an electronic device designed to make high voltage ac (i.e., 120Vac) from a dc source of electricity, i.e., a battery.

dc power

What is dc? dc is direct current electricity. It's the kind of electricity that flows from a battery. 12Vdc is a standard worldwide. Unabbreviated, this is electricity at 12 Volts of potential and direct current. 12Vdc is a standard used in the electrical systems of automobiles and trucks, RVs (recreational vehicles), and marine applications. Most importantly, 12Vdc is the most common standard for the output of solar-electric (PV) modules, wind-electric machines, and microhydro-electric turbines.

System vs. battery voltage

Don't confuse the electrical standard of the 12Vdc system with that of the 12V battery. By definition, a battery is composed of two or more electrochemical cells. Since one electrochemical cell using lead-acid technol-

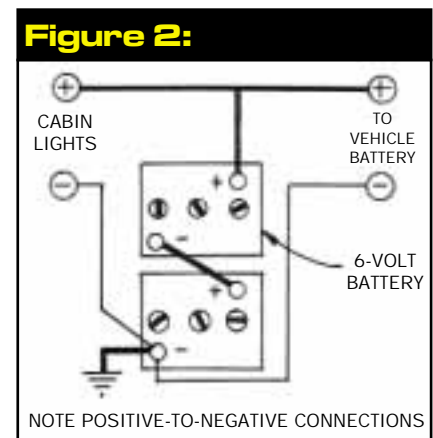
ogy can produce a maximum of a little more than two volts (or 2.1V), six cells are combined to produce a 12V battery. In the automobile, the battery and the electrical system are both 12Vdc as a matter of convenience.

However, in golf carts, marine applications, and RE systems the standard battery is three cells, or 6 Volts. To work in a 12Vdc system, two (2) of the 6V batteries are connected in series, adding their voltages together (Fig. 2).

Why not stick with using one 12V battery versus two 6V batteries in a 12Vdc system?

In the automobile, the 12V battery's mission is defined by its type, SLI. SLI stands for "starting-lighting-ignition." Powering the starter motor to fire up the engine requires hundreds of Amps of dc current until the engine starts. The Amp (after Ampere) is a measure of the rate of flow of electrical current. The short duration (seconds?) of this high power level represents a relatively shallow depth of discharge of the battery. This energy is immediately replenished by electricity from the engine-driven alternator, which thereafter handles all 12V electrical loads in the vehicle.

In dc systems, batteries store energy in varying amounts as it is available (from sun, wind, and flowing water) and ladle it out over a period of time. This results in a deeper depth of dis-



Series-wired 6V batteries for a 12V system.

charge of the batteries *and* a less-certain time period before recharging is started or completed. The thin plates inside of SLI-type batteries are damaged by the deep discharge and slow recharging in this application. The solution is thicker plates. There is insufficient room for thick plates inside the small case of a 12V battery in a car. However, there is room in the same size of case for three cells of thick plates. or 6V. This explains why manufacturers make a 6V battery.

Fortunately, a thicker plate represents one way to increase ampacity. (Ampacity is one measure of battery capacity, often written as Ampere-hour, or Ah.). Therefore, a 6V, 220Ah battery has roughly the equivalent amount of energy as a 12V, 110Ah. At 65-75 pounds each, this is about as heavy a battery as anyone is likely to be able to load, tote, unload, and position by one's self.

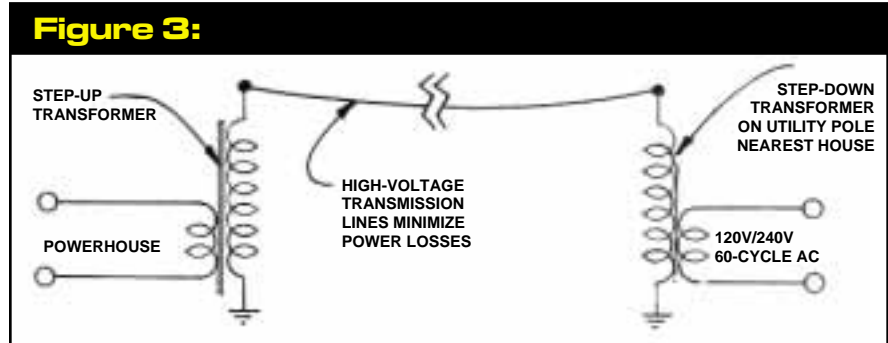
To sum up: The 12V SLI battery has high *power* density and wants immediate replenishment. The 6V deep-cycle battery has high *energy* density and a capacity to withstand repeated deep discharge. *Never use anything less than a deep-cycle battery in an RE system.*

ac vs. dc

To recap, ac (alternating current) is what you get from the standard wall socket and dc (direct current) is what comes out of batteries. Which is better—ac or dc?

dc dominates in the RE system in terms of collecting energy and storing it. Again, the most common standard for the output of photovoltaic (PV) modules, wind-electric machines, and microhydro-electric turbines is 12Vdc. Batteries are a natural for dc systems, too. Batteries won't accept ac—it makes them fume, smoke, and get hot. There is no way to store ac unless it is converted to dc first. With the battery, it is dc in and dc out.

ac dominates in the world of utility-generated power. This is understandable. Without ac electricity, there



Utilities use AC and high-voltage as a means to deliver power long distances.

would be no way for the utility company to efficiently transfer power from the generating station to your home. In fact, it was the discovery of the ac generator by Nikola Tesla that solved the problem Edison was experiencing in transferring dc power further than a few blocks from the generating station (see **Sidebar A**).

Low vs. high voltage

Another big difference between the standard of 120Vac and the standard of 12Vdc is the difference of voltage itself. The ac standard is nearly 10 times the voltage of the dc one. Why?

Imagine this scene. It's raining, the vehicle's hood is open, and someone has arms, hands, and fingers probing and touching inside the engine compartment.

This is *no* place for high voltage. Even if you're standing in a rain puddle and touching the positive terminal of your 12V battery, it's unlikely you would feel (or be) shocked. Ergo, the beauty of the 12Vdc standard.

The 120Vac in your home is much more deadly. With this voltage, if you touch a bare wire you won't forget it quickly. You will feel a jolt (that's your muscles seizing up) and the jolt will probably kick you off the wire. Fortunately, the advent of strict electrical codes in circuitry and appliances, proper grounding, and the GFI (ground fault interrupt) protection afforded in bathroom, kitchen, and garages—all work to ensure sufficient isolation between you and 120Vac in home and shop.

High voltage is convenient in the home and shop because even for relatively short distances, 120V is more efficient at transferring power than 12V for the same size of wire (see **Fig. 4** and **Sidebar B**).

Line losses are expressed in another way: as voltage "drop." If you notice a lightbulb dim as a motor starts up or a power tool is operated on the same 120Vac circuit, you're witnessing voltage drop. This is analogous to the loss of pressure you might feel in the shower spray as a nearby toilet is flushed.

At 12V, for the same amount of power transfer over the same size of wire, the voltage drop is amplified and the lightbulb will dim to a dull reddish glow. This dimness adversely affects the *frequency* (or quality) of light, whereas a light dimmer switch affects the *quantity* or average current of light. Line losses which are barely noticeable at 120V are intolerable at 12V, and are incapable of adequately operating the load.

In dc circuits of low voltage, the only way to minimize line losses is to use shorter runs of wire. Or wire of a much larger size. Usually it's both—a short run of large wire. Many times, this requires only some forethought and planning since it's usually possible to locate high power dc loads close to the battery bank that feeds them.

Another way to minimize line losses is to convert low voltage dc to 120Vac in the electronic inverter. At \$0.75 to \$1.00 per watt, this is an expensive way to avoid line losses. Still, in RE

Sidebar A: ac vs. dc.

What's this thing about ac anyway? A little history lesson might be in order. It all started when Edison built the first incandescent bulb and the power station to light it.

A big disadvantage of DC electricity immediately revealed itself: you couldn't build the powerhouses any further than a few blocks from where the electricity was produced. Why? The resistance of the wire consumed a portion of the power. Houses close to the power station had brilliant lights and those at the furthestmost reach had dim ones. The last guy on the line had it bad. When someone close to the powerhouse turned on a whole bunch of lights, his would dim even further. And pity the poor farmer! He couldn't get any power out there in the country until a few companies got smart and started manufacturing wind-electric machines.

Then along came Nikola Tesla, the father of ac motors and generators. If you make ac at any voltage, it can be transformed—through use of the highly-efficient transformer—to any other voltage (Fig. 3). Stepping up the voltage has the effect of stepping down the current for the same power transfer.

Why does this matter? Power delivered to the "load" (anything which uses

power) is defined as the product of Amps and Volts, or $P=IV$. On the other hand, line losses (the energy lost in the transmission wires) are determined by the product of Amps squared times ohms (the resistance of the wire), or $P=I^2R$. Note that voltage plays no part in line losses. With ac, then, the transformer stepped up the voltage (or down, depending on the ratio of the number of windings of input and output) to hundreds of thousands of Volts. Naturally, since "power out" must equal "power in" (minus losses), the ac current decreased in the same proportion. Thus, super-high voltage and super-low current meant very low line losses irrespective of how far you needed to send it.

Of course, very high voltage is dangerous stuff for appliances, lights, and

motors. With ac, however, once you get the power to the home, farm, or shop, a second transformer (on the utility pole) would step the voltage back down for use.

The point of this historical review? There's nothing really "sacrosanct" about 120-volt, 60-cycle ac. It is convenient for the utilities to use because it's the only way they have to transfer power over long distances. If your power is homegrown, you don't have their problems, so why necessarily accept their solution? True, after you've considered all the factors, you may decide that high voltage will work best for you in your situation. Fine. Still, explore this topic closely. Low voltage and dc have a lot to offer.

Sidebar B: Low vs. high voltage

Nikola Tesla's invention of the ac generator solved the problem of power transmission through wires over long distances. This also works on a smaller scale in a home. Even the best electrical wire has some resistance to the flow of power. For any given size and length of electrical wire, if you double the current you

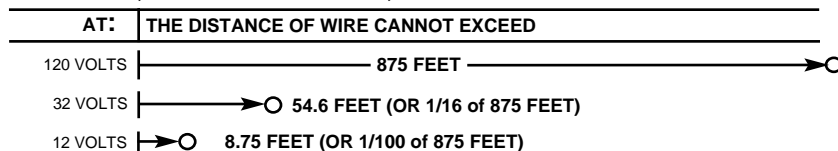
send through it, the losses in heating the wire are four times as great.

For example, suppose that we wanted to deliver power to a 1,200-watt load. At 120V, this would be 10 Amps. At 12V, it would take 100 Amps to deliver 1,200 Watts of power. The difference in the heating effect of the wire—at ten squared—is 100 times as much for 12V as for 120V.

Increasing the size (gauge) of the electrical wire is one way to decrease this resistance. This is a simple (yet more expensive) way to minimize line losses for a run of even a few hundred feet at 12V. Of course, smaller loads pull less current and suffer less losses even over large distances.

Figure 4:

With #14 WIRE, AN ALLOWABLE 5% LOSS, AND A 240-WATT LOAD



Line losses are greater with 12V than 120V.

systems that require 120Vac for some loads, an increase in the wattage rating of the inverter might be justified on the basis of the savings in costly runs of larger wire. However, altogether eliminating the use of dc power is taking matters to the extreme.

the ac-only trend

Today's average-to-large RE systems are using two strategies to minimize transmission line losses: greater-than-12V dc energy collection (and storage) and ac-only loads.

a. greater-than-12V dc energy collection (and storage). In this trend, equipment designed to collect energy from solar, wind, and hydro-electric sources and the battery bank are wired to a higher dc voltage. There are many choices of dc system voltage—i.e.,

24V, 32V, 36V, 48V, and 120V. Solar (PV) modules of the same rating may be wired in series to reach any multiple of 12V. The alternators in wind-electric machines or hydro-electric turbines may be re-wired to work at higher voltages or re-wound to produce power at lower RPM. Any of these methods will prove helpful in routing most of the collected power to the batteries.

Conveniently, inverters with these input voltages (24V, 32V, 36V, 48V, and 120V) are available with a fairly wide range of wattage ratings (50-4,000 Watts and higher). Today's inverter—given the good efficiency over its full range of wattage capacity and with energy-saving “sensing” features—is able to help the most remote RE system feel as if it were grid-connected.

b. ac-only loads. Installers, whether independent contractors or the owners themselves, are easily lured into the one-voltage system, i.e., an ac-only system. Sure, a dc voltage is present in the battery room, but it stays there. An ac-only design eliminates the extra dc hardware—i.e., switches, circuit breaker, fuse or distribution boxes, and special outlets—and permits standard wiring (sizes) in the household.

Where the decision to use ac-only electricity is made during a planning stage, another trend is often set in motion. Since it is more efficient to transfer power at 120Vac than at lower voltages (ac or dc), there is the temptation to locate the inverter at some distance from the house in the direction of the biggest energy source. Think about it. Once that 12V, 24V, 32V, 36V, or 48V of generated electricity is converted to 120Vac, the size (gauge) of the transmission line (wire) can be reduced. And, since the battery pack should be located near the inverter it feeds, both battery pack and inverter are located away from the house.

When a standby generator is part of the energy equation, there is additional incentive to build a separate out-

building to house (and quiet) the generator and to locate both battery bank and inverter within it. Combined with the attractiveness of transferring power at 120Vac, this scenario is likely to result in an outbuilding located still further away from house and shop.

An energy system based on this domino-style of planning is flawed. It precludes use of dc in a distant house for transmission loss reasons.

Hybrid ac/dc use

I believe the energy system with the strongest merit is one that fully utilizes 12Vdc and 120Vac, as needed. The use of dc and ac together in one system requires some planning (see **Sidebar C**) and duplicates some circuitry. Still, the two voltages are more complementary with one another than they are contrary.

Altogether, I can offer a dozen reasons why retaining 12Vdc is a worthwhile effort.

1. It's there. The 12Vdc is free. Unused, it's just storage battery voltage. You need only tap it. Using 12Vdc, then, adheres to the KISS principle. That is, keep it simple, silly. Furthermore, any loads that are more easily, efficiently, or inexpensively powered by 12Vdc directly will minimize the list of loads that must be powered at 120Vac. This reduces both the size and cost of inverter required in the RE system.

2. Availability of 12V stuff. There is widespread availability of appliances, tools, motors, and lights that are designed to run directly on 12Vdc. The RV (recreational vehicle) market is one of the best sources for these loads. Other sources are automotive, marine, and hobby markets. Realize that many RE systems today,

Figure 5:

Amps in Wire	Wattage at 120 Volts	WIRE SIZE										
		#14	#12	#10	#8	#6	#4	#2	1/0	2/0	3/0	
1	120	—	—	—	—	—	—	—	—	—	—	—
2	240	563	875	—	—	—	—	—	—	—	—	—
4	480	250	438	688	—	—	—	—	—	—	—	—
6	720	188	300	438	750	—	—	—	—	—	—	—
8	960	138	213	363	563	888	—	—	—	—	—	—
10	1,200	113	175	288	450	713	—	—	—	—	—	—
15	1,800	75.0	113	175	300	475	750	—	—	—	—	—
20	2,400	50.0	87.5	138	225	363	563	900	—	—	—	—
25	3,000	40.0	70.0	113	175	288	450	725	—	—	—	—
30	3,600	37.5	60.0	87.5	150	238	375	600	963	—	—	—
40	4,800	—	—	70.0	113	175	288	450	725	900	—	—
50	6,000	—	—	57.5	90.0	138	228	383	575	725	913	—

Amps in Wire	Wattage at 12 Volts	DISTANCE IN FEET										
		#14	#12	#10	#8	#6	#4	#2	1/0	2/0	3/0	
1	12	113	175	275	450	710	—	—	—	—	—	—
2	24	56.3	87.5	138	225	355	575	900	—	—	—	—
4	48	25.0	43.8	68.8	113	178	288	450	725	900	—	—
6	72	18.8	30.0	43.8	75.0	119	188	300	481	600	760	—
8	96	13.8	21.3	36.3	56.3	88.8	144	225	363	450	570	—
10	120	11.3	17.5	28.8	45.0	71.3	113	180	290	360	457	—
15	180	07.7	11.3	17.5	30.0	47.5	75.0	120	193	240	304	—
20	240	05.0	08.8	13.8	22.5	36.3	56.3	90.0	145	180	229	—
25	300	04.0	07.0	11.3	17.5	28.8	45.0	72.5	115	145	183	—
30	360	03.8	06.0	08.8	15.0	23.8	37.5	60.0	96.3	120	152	—
40	480	—	—	07.0	11.3	17.5	28.8	45.0	72.5	90.0	114	—
50	600	—	—	05.8	09.0	13.8	22.8	36.3	57.5	72.5	91.3	—

■ Exceeds Ampacity
 ■ Over 1,000 Feet
 ■ Check ampacity

This table allows 5% line loss for 12V and 120V circuits.

Sidebar C: Using ac and dc together

There are a number of issues to using ac and dc together in the same RE system. Briefly, they are: circuit boxes and hardware, outlets, wiring schemes and sizes, and switches.

- **Circuit boxes:** The Electrical Code prohibits ac and dc in the same box. You'll need two distribution boxes—one for ac and one for dc. Circuit breakers rated for ac won't work for dc. Expect to pay more for dc breakers. On the other hand, fuses are mostly indifferent to ac or dc, or even differences in voltage. Older-style circuit boxes employing fuses that no longer meet Code for ac wiring will work fine for dc circuits. Up to ratings of 30 Amps, the new style of automotive fuses are also great for dc systems.

- **Outlets:** Standard receptacles will work for dc or ac. You must exercise caution in using both in the same household. Plugging a 12Vdc load into a 120Vac socket may fry the load if the circuit breaker/fuse doesn't pop first. Plugging a 120Vac load into a 12Vdc circuit may hurt the load or blow a fuse—or simply do nothing. Still, who needs this worry.

Amateur electricians have many ways to handle this situation. One scheme uses the same type of receptacle for ac and dc circuits but color-codes or labels the receptacle plate itself. This works okay for hermits but it's lousy for guests, children, and the uninformed. A second scheme is to wire ac and dc into the same receptacle, with a shared common (bad idea). Another scheme is to wire the 12V appliances to a unique auto cigarette lighter plug/receptacle (light loads only, please). Or a plug/receptacle of the style found in older RVs (recreational vehicles) for 12V circuits (mostly inadequate).

A better idea is to use a plug/receptacle with a different NEMA number (pattern) for the 12V circuit (shop around for the least expensive type). This usually changes the orientation of

the plug blades so that it's impossible to mix 12Vdc and 120Vac loads and circuits. Add the appropriate plug to each 12V load.

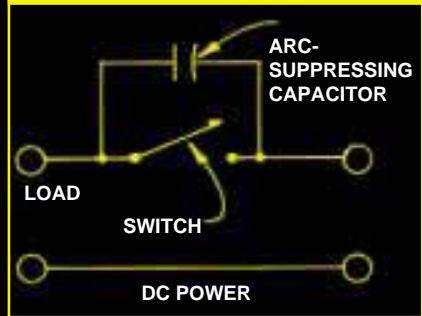
Polarity is another issue with dc. Incandescent lights and simple heating circuits don't really care about polarity, but you must observe proper polarity (pos. or neg.) for LEDs, high-frequency fluorescent lamps, stereos, and many other dc loads. This is easily handled by the newer style of plugs and receptacles that permit insertion in only one way. These will ensure correct polarity in wiring plug and receptacle, as will the use of 3-prong plugs.

- **Wiring:** Overall, 12Vdc wiring will require a larger gauge of wire for even modest loads. Wire size increases rapidly with any length. Here, preparation and creativity go a long way toward minimizing the expense and labor while retaining full capability. What do you want to do and where? Special low-voltage wiring tables will assist you in sizing wire for specific loads at varying distances (Fig. 5). There is also merit in the idea of running a branch line of large wire to the far side of the house where it can be distributed from a second, smaller fuse box to loads in that area.

Large-gauge wire is stiff and awkward to route; plan accordingly. Use 12-gauge wire "fingers" from a bigger gauge wire to ease connections to receptacles and switches. Use junction boxes for wire gauges of #8 and larger. Relatively short lengths of #12 wire leading from these to loads and receptacles will incur only small losses.

- **Switches:** Switches designed to handle 120Vac may fail in use with 12Vdc. The arc produced when a standard ac lightswitch opens (turns off) a dc circuit will be hotter and last longer. Absolutely avoid "silent" switch types; they open way too slow. Either way, the dc arc will eventually (if not immediately) burn a switch's contacts. It is possible to add a capacitor across the switch to suppress this arc (Fig. 6). Or to wire a

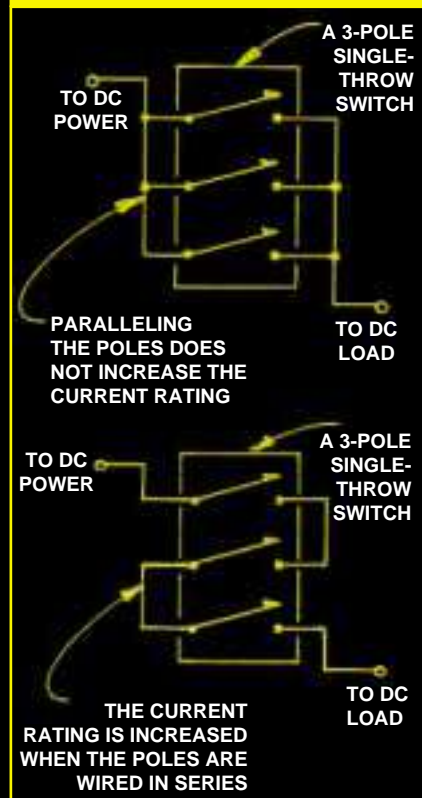
Figure 6:



A capacitor will reduce arcing in a switch in a DC circuit.

switch with multiple poles in series (not parallel; see Fig. 7) to help it survive this arc. Of course, you may also find and install switches rated to switch dc current.

Figure 7:



Series-wiring of multiple-pole switches reduces arcing.

particularly smaller systems, are primarily dc. If there is an inverter, it's a small one that handles only a few ac loads.

3. Reliability. The reliability of any system is no greater than the reliability of its weakest part. Reliability and simplicity go hand in hand. The fewer the parts in a system, the fewer the things that can go wrong. Inverters are expensive, high-tech black boxes containing hundreds of components. The failure of one component will make the inverter inoperative. When inverters fail, they must be shipped off for repair. Are you willing to run a standby generator (if you have one) to power even the smallest loads (i.e., lights) until it's fixed and returned to you weeks later?

4. Lighting. Lighting is one example of loads that are best served by 12Vdc, irrespective of their type—incandescent, fluorescent, or LED.

a. Incandescent bulbs. The filaments of incandescent bulbs are actually being turned on-and-off 120 times per second from 60-cycle ac, 120V electricity. You may not see it but the filament feels this shock. The same bulbs on dc (i.e., at 120V) have a smooth flow of electricity and last 2-3 times longer. Also, a 50-watt incandescent bulb at 120V draws about 0.4A Amps whereas at 12V it draws about 4 Amps. High-current filaments are more efficient than low-current filaments in lower wattages found in households.

b. Fluorescent bulbs. Fluorescents working on 120Vac have a bad reputation, primarily because of the 60Hz (cycle) flicker. Quality fluorescents designed for 12Vdc use higher frequencies (i.e., 5-20kHz) in their circuitry. This eliminates flicker and increases the overall efficiency.

c. LEDs. Light-emitting diodes (LEDs) are super-high efficiency lights that work on low-voltage dc. Four LEDs wired in series with a resistor (to limit current) work directly on 12Vdc (observe polarity). Available in five hues—red, amber,

green, blue, and white—LEDs may be arranged in clusters (in multiples of four) in lamps for reading, spot, and general lighting needs. The new flashlights using LEDs and rechargeable NMH (nickel metal hydride) cells are fantastic. There are no incandescent or fluorescent bulbs that come close to the efficiency, service life, and overall cost-effectiveness of LEDs.

The well-designed lighting system will use a combination of incandescents, fluorescents, and LED lamps. Generally, use incandescents for short-duration and high-illumination tasks, fluorescents for long-duration and medium-illumination, and LEDs for everything else.

5. Toll charges. "Direct use of" electricity, in whatever form (i.e., 12Vdc) is always more efficient than converting it to another form (i.e., 120Vac). Anytime power is converted or transferred, a toll charge is involved. Inverters are most efficient in the mid-to-upper wattage range. Even if 95% efficient at lower wattages, realize that this means that 5% of the energy is lost. This amount equals the acceptable line losses in most household wiring circuits at 120Vac.

6. Duplicity. There are many loads in the home and shop that are powered by 120Vac circuits but they actually *operate* on low-voltage dc, often 12Vdc. On the inside, then, the 120Vac is stepped down to a lower ac voltage which is then rectified into dc. (Or a black module plugs into the wall and a plug is inserted into the device.) Stereos, many computers, answering machines, and any loads that also may be powered from AA, C, and D batteries are working at 12Vdc or less.

Some loads may be powered directly from a 12Vdc circuit. Use some method of reducing the voltage—i.e., a converter, the selection of a suitable dropping resistor, etc.—for less-than-12V loads. Stereos and computers lacking an external jack may be modified at an electronics (radio/TV/VCR shop) to provide this access (observe

polarity). Is this process worth the effort? There is a certain absurdity to converting 12Vdc to 120Vac in an inverter, then converting the 120Vac back to 12Vdc (or less) for operating a load that, with some forethought, could circumvent these processes.

7. Battery SOC. All batteries are not created equal. Manufacturing variances, electrolyte differences, temperature differences, and battery age—all affect the SOC (state of charge) of a battery in a pack. When a battery pack is wired for voltages of 24Vdc or higher, these variances can only be minimized by periodic "equalizing charges." This is an eloquent phrase for overcharging the entire pack. To bring the weakest batteries into line means overcharging the best batteries. Conversely, when wired as a 12Vdc system, batteries in the pack receive the charge they need without adversely affecting the others.

8. Load efficiency. There is virtually no incentive in industry to include efficiency as a factor in the design and manufacture of appliances, tools, motors, lights, and electronics that operate from utility-supplied 120Vac. Unfortunately, any inefficiency is too easily hidden in the cost of operating these loads over their service life. Efficiency always adds cost to a product. Thus, the "down side" of competition in the marketplace is that low cost reigns as a design factor over efficiency.

This anomaly was revealed over a six-year period in working with all types of RE systems, where every watt counts. It inspired me to write the book Better Use Of. The power consumption of devices working at 12Vdc sometimes proved less than devices powered at 120Vac, sometimes by a factor or two or more.

Working with ac-only RE systems perpetuates this trend—many of the utility-based 120Vac loads are simply carried over. Even where an effort is made to rid the inventory of superfluous loads, rarely is the efficiency of any specific load analyzed by the

owner. When the system bogs down eventually, the focus is on more energy collectors, more batteries, a bigger inverter, buying a standby generator (or one bigger than the existing one).

In the past two decades, the concept of the negawatt—applied to industrial consumption—clearly illustrates that the best cost/benefit ratio is in conservation rather than more power plants. Increasing generating capacity to compensate for those losses is an expensive option—for the utilities and RE system owners alike.

9. Power vs. voltage. Power production, particularly with today's wind-electric and hydro-electric machines, begins when the generated voltage exceeds battery pack voltage and current begins to flow. Here, the 12Vdc system is better able to take advantage of windspeeds/water flows than higher system voltages (i.e., 24V, 32V, 36V, 48V, etc.) because the generator/turbines must spin to a higher rpm to reach the voltage needed for current to begin flowing.

Admittedly, the real power in wind (more so than water) is in higher windspeeds, and manufacturers must balance many factors to produce a unit that operates over a wide range of conditions. However, without power conditioning (an electronic way of

matching voltages between energy collection and battery pack), it's a simple truth that an alternator or generator cannot reach higher voltages without passing through 12V first. This can make or break an RE system in areas of marginal energy availability.

10. Emergency energy production. One major factor in favor of an RE system based on 12Vdc is that the battery pack may, in an emergency, be recharged from the alternator in a car or truck.

Indeed, many fledgling RE systems have their roots in this method. Like many folks involved in the back-to-the-land movement, I slowly built a house and gardens, developed the water system, and erected a wind machine. My first renewable energy system was a few extra batteries I added to the truck that were charged up whenever we drove this vehicle. Lights, tools, and appliances plugged into this mobile battery pack when I was on the land. If the 12Vdc system's battery pack got too low before I was ready for another trip, I just started the vehicle's engine, set a fast idle, and quickly recharged the batteries.

Once my wind-electric system was online, my battery pack was removed

from the truck and became a stationary one. Rather than buy a standby generator, though, I retained the circuitry in the truck and used it in the winter for recharging my battery pack (via a cord) as needed. It certainly proved quieter than a standby generator. In practice, it proved no less efficient than the small gas engine used in standby generators and losses in the battery charger that converts the 120Vac to dc for storage in the battery pack.

If you don't feel adept at performing the in-vehicle wiring yourself (see **Sidebar D**), get an electrician or a competent auto mechanic to help you.

11. RE system savvy. Most people are interested in what electricity will *do* for them, and are less concerned with *how* it does it. This explains why most people are content to be connected to the utility grid. Or why they will purchase and use an RE system that *feels* like it's connected to the grid no matter how remote their site. Does this type of system offer independence or self-reliance? No—it only changes the source of the dependence. A 120Vac-only system can maintain the same level of ignorance that exists for most utility customers.

One of the merits of dealing with a voltage other than 120Vac is how it

Sidebar D: An emergency 12Vdc charging source

Vehicle (car or truck) alternators are designed to spin fast enough even at curb idle to recharge the vehicle's SLI battery. At fast idle, the charge rate can actually approach the alternator's output (current) rating. For this reason, a vehicle's 12Vdc system will recharge additional batteries, onboard or offboard.

There are two ways to do this. One method merely adds wiring and components to the existing system (**Fig 8** and **Fig 9**), much like an auxiliary battery in an RV is charged from the engine's alternator. This design also ensures that the SLI battery will start

the engine whenever it's needed. A second method modifies the vehicle's existing charging circuitry to eliminate the vehicle's SLI battery from the circuit during charging to ensure full field current to the alternator and maximum output. This is trickier; get some help.

There are several precautions in using a vehicle as an emergency system for charging a 12Vdc system. First, keep the vehicle's engine hood open to help facilitate the better cooling that the alternator normally gets when the vehicle is driven. At higher outputs, the alternator will get hot. Second, never use the vehicle's SLI

battery for powering a cabin. It won't survive deep cycles *and* you risk a dead battery when you want to start the engine. And, three, ensure that the alternator's field windings never see more than 12Vdc.

With a few additional changes, this setup will also charge battery packs of 24V (or higher). Of course, the engine idle must be advanced further. An alternator is actually capable of producing 120Vdc. Careful. Eddy current losses will result in more heat. Use an ammeter to measure output current and back off from the current rating of the alternator at higher voltage.

challenges an owner to understand it and the entire RE system. For example, the 12Vdc output of most energy collectors (PV modules, wind generators, and microhydro turbines) and loads are rated in Watts and amps, while the capacity of battery packs involves amp-hours. With one voltmeter and ammeter, an owner is able to estimate the day's production of energy (amps times hours), determine

the battery pack's state-of-charge (observe the voltage under load) and easily calculate the effect any load will have on this reserve (amps times hours).

By comparison, 120Vac supplied from the utility will use kWh (kilo-Watt-hour) for the energy consumed and Wattage (Watts) for loads and standby generator output. This requires a kWh meter (complex and expensive) and a conversion process for all of the dc processes involved.

Generally, I have found the owners of RE systems—dc-only (12Vdc) or dc/ac (12Vdc and 120Vac)—to be quite conversant about their systems. I cannot say the same for owners of 120Vac-only systems. The ability to troubleshoot a problem or effectively surmount a shortcoming is directly proportional to one's understanding of the system.

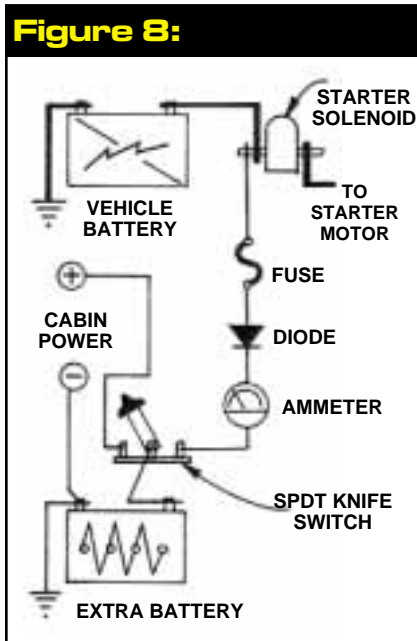
12. dc-to-dc conversion. The cost of the size of wire needed to transfer power at low voltages (i.e., 12Vdc) is offered as a primary justification for 120Vac-only RE systems. However, the same technology that makes today's inverters so efficient is also available in smaller packages to more directly address issues of power transmission.

This dc-to-dc technology steps up the low voltage dc output from solar

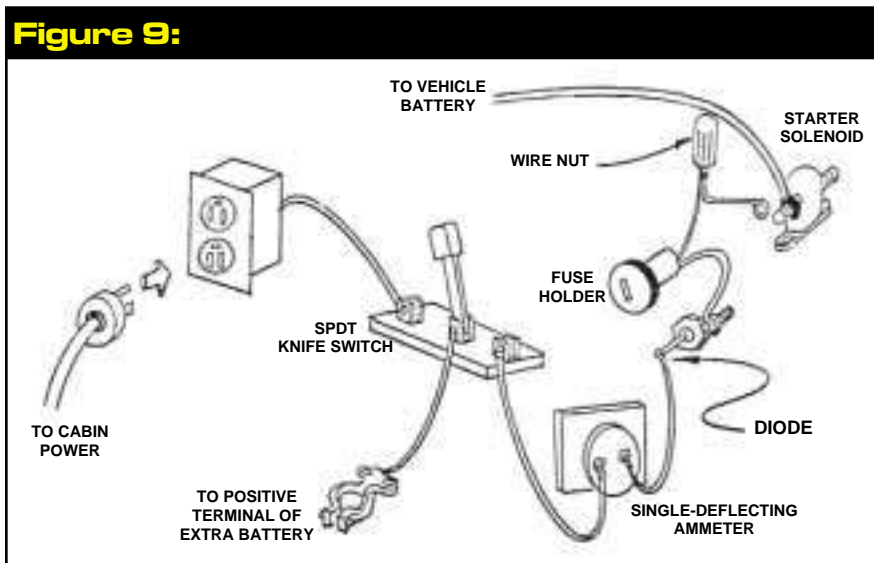
(PV) modules and wind and microhydro generators to a higher dc voltage for transmission to the batteries over smaller, less expensive wires. The voltage is then stepped back down to 12Vdc at the battery pack. This high frequency dc is more efficient than the 60-cycle ac output from an inverter over long distances. This technique is so efficient that utilities are now installing high-voltage dc transmission lines because they are less problematic than ones using ac. Check into this before you commit to a 120Vac-only system.

Final comments

Evaluate your RE system—whether installed, on the drawing board, or still a pipe dream—for the merits afforded in using both low-voltage dc and high-voltage ac. With good planning, downsizing the 120Vac-only side of the system will balance the cost and versatility of retaining a 12Vdc option. Even if it doesn't, consider this saying: The bitterness of low quality is remembered long after the sweetness of low cost is forgotten.



Schematic for battery charging from a vehicle.



Wiring diagram for deep-cycle battery charging from vehicle.



Michael Hackleman

(Some drawings and photos in the article were taken from: *At Home with Alternative Energy*, (Michael Hackleman, Peace Press, 1980, pp 147) and *The Homebuilt Wind-Generated Electricity Handbook* (Michael Hackleman, Peace Press, 1975, pp 194). Send an SASE to Michael Hackleman, P.O. Box 327, Willits, CA 95490 for a current publications list. Δ