Desert Moon House
A super-low EMF solar electric system

This article is part of a series about a less-toxic and super-low EMF house in northeastern Arizona. In this article, the 12 volt electrical system and appliances are described.

Keywords: off-grid, solar electricity, low EMF, 12 volt, propane refrigerator, electrical hypersensitivity

Why move off the grid?

The author decided to move off-grid for several reasons. The most important was simply feeling better in a super-low EMF house, rather than just a low-EMF house.

With an off-grid house, it was possible to build in an area far from the electrical grid. As most people want the convenience of grid power, off-grid areas are sparsely populated, slow to develop and land prices are much lower. This means there are no ground currents and little toxic drift and electrosmog from neighbors.

Cell towers use a lot of electricity, so they are rarely placed in off-grid areas.

Off-grid living has many health benefits, but it is a major lifestyle change and it is not suitable for all people. People who require push-button convenience and lack basic technical skills are not good candidates.

Choosing 12 volt DC

Almost all off-grid houses in America use an inverter to generate 120 volt AC electricity, so regular lights and appliances can be used. However, inverters put out very high levels of dirty electricity (transients), which radiates off all the household wiring. This is a problem even with the best sinewave inverters.

A simple AM radio, set to the lowest number on the dial, will pick up the radiation from the household wires, if put next to an extension cord or other exposed wire.

Some types of dirty electricity can be measured with a Stetzer meter. The inverters measured by this author all sent the meter off the scale.

The dirty electricity from an inverter is so strong it is not feasible to clean it up with filters.

DC electricity is healthier than even the cleanest AC electricity, as it runs smoother without fluctuating 60 times a second (50 times outside North America). This author simply feels better with DC.

A DC system can use various voltages, with 12 and 24 volts being the most common. Twelve volt was chosen as it is the simplest and has the most choices of appliances. With a larger system, it might have been necessary to use both 12 and 24 volt.

System overview

The system is rather simple and modest, compared to what is used in many modern off-grid houses in America. A super-low EMF house usually doesn't need a lot of electricity.

The system is sized to run two small pumps and some lights in the house during the Arizona winter, without needing a generator to charge the batteries. A battery charger creates a lot of dirty electricity, so none is ever used.

The Arizona climate is excellent for solar systems. There is an average of five hours of sunshine every day in the winter, with two consecutive days of overcast during the occasional winter storm.

The house has two separate solar systems, which each have their own solar panels and battery banks. One system powers the house while the other powers the two pumps.

Having two separate systems adds little extra cost, but provides a number of benefits.

With one battery bank, it would be necessary to use more costly types of batteries in this case (see the section about the batteries).

Each battery bank can cover the essential load in an emergency, providing a backup. This could be particularly handy during a winter storm, where the circulation pump for the heating system is critical. A battery bank could get depleted in a number of ways, such as if the water pump keeps running because of a leaky toilet or a stuck off-switch, and nobody is home to notice it.

This is not a problem in this household, but some people may have a problem staying within their energy budget and deplete their batteries that way. With critical functions on a separate solar system, such a home would not lose heat and water. This could especially be an issue for folks with poor memory functioning, dementia, etc. Or for folks who just have their minds elsewhere.

Having two systems can also isolate dirty electricity from the house. The dirty electricity from the two pumps turned out not to be a problem here, as the pressure pump only runs briefly and the circulation pump puts out very little. It was originally planned to later put a 12 volt DC freezer on the secondary system (with an additional solar panel), which would have created a lot more dirty electricity. This extra refrigeration capacity was not needed and never installed.

The author sometimes uses the secondary system for testing equipment and other experiments that are best kept on a separate system.

The solar panels

There are six Unisolar 64 watt panels mounted on a pole in the front yard, next to the outbuilding. They are close to the battery bank to avoid line losses, which are very important in a low-voltage system.

The solar panels could have been mounted on the roof of the outbuilding, but a polemount was chosen so it is easy to brush off snow. The rack can also be tilted seasonally to better catch the sun. It turned out that the batteries are always full midmorning in the summer, so there is no need to tilt the rack to optimally catch the summer sun. The rack is now left at optimal winter tilt all year round.

There is no tracker, i.e. the solar panels do not turn to follow the sun as it travels across the sky during the day. A tracker can make the panels produce more electricity during a summer day, but not much extra on the short winter days. Trackers are costly and it was much more cost effective to buy an extra solar panel, as the most electricity is needed during the winter in this household.

The six solar panels are divided into two groups. Four panels (256 watts) charge the main battery bank that powers the house. The two other panels (128 watts) charge a separate battery that powers the water pressure pump and the small circulation pump for the in-floor heating system. The 128 watts of solar panels are nearly twice what is normally needed for the two pumps, but this is a critical system that is used the most during winter storms when there is little sunlight for days. It is over-engineered eleven months of the year, but perfect for dark winter days.

The combiner/breaker box mounted on the pole holding the six solar panels. There is a breaker for each solar panel. The box is shared between the two solar systems, but each system is wired separately. One solar panel is wired so it can operate separately, for experimental purposes. The shiny round lightning arrestor can be seen in the bottom center.

The solar panels were purchased in 2007 when a 64 watt panel was a common size. The prices have since dropped dramatically and panel sizes are now much larger. Higher voltage panels are now the norm also, so someone wanting to build a 12 volt system will have to make sure a panel is for 12 volt.

The batteries

The batteries are housed in the outbuilding. They emit hydrogen gas when they are nearly fully charged, which means they must be kept away from both living quarters and any flames (such as the propane water heater). The gassing is most notable in the winter, where the batteries are charged at a slightly higher voltage because they are cooler.

The outbuilding is lightly heated, so it typically is around 50ºF (10ºC) on a winter day. This is both to prevent the pipes from freezing and to keep the batteries from becoming too cold. Batteries cannot hold much electricity when they are cold.

The main battery bank with six low-cost golf cart batteries.

There are six golf cart batteries in the main battery bank. Each battery holds 220 amp-hours of electricity at 6 volt. When two batteries are connected in series, they have 12 volt and 220 amp-hours.

This battery bank has three parallel strings, each of two batteries. The total capacity is 660 amp-hours at 12 volt.

The secondary battery bank has just two golf cart batteries in it.

If there had been only one battery bank to handle the entire load, it would have been necessary to use the more expensive L16 type batteries. L16s have a larger capacity, so six would be enough instead of eight golf cart batteries. Eight batteries would cause uneven charging due to too many parallel strings, so the batteries wouldn't last as long.

The first set of batteries lasted four years, which is what one can expect from low-cost golf cart batteries that are well maintained. The first set was purchased from a golf cart store, the second set from an auto supply store. L16 batteries are a little harder to find locally.

Charge controllers

A charge controller makes sure that the batteries are not over charged, which would eventually damage them. Modern controllers use electronics to charge the batteries more efficiently, using methods called Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT). These features create a lot of dirty electricity, so they cannot be used in a super-low EMF house. It is very difficult to find a charge controller without PWM and MPPT.

During the first years, the main system used a vintage Trace C30A+ controller from 1994. Today a voltage-controlled switch with a blocking diode is used. The diode prevents electricity from running backwards to the solar panels at night.

The voltage switch avoids the problems of PWM and MPPT. The electronics inside the voltage switch sometimes sends out small amounts of dirty electricity, which is controlled by installing a capacitor (about 4 microfarad) across the wires supplying electricity to the circuit board.

As a battery gets charged, the voltage rises. At a certain voltage, the battery is full and the solar panels are switched off. This voltage depends on the temperature of the battery. Sophisticated charge controllers do this automatically, but here it has to be adjusted manually every three weeks during spring and fall. The temperature is more stable during summer and winter, where the setting is left unchanged.

Vintage Trace charge controller from circa 1994.

Voltage controlled switch (active high) from Solar Converters Inc., with a blocking diode on top and breaker box to the right.

Adjusting the voltage switch takes about two minutes, using a voltmeter and a small screwdriver.

See the reference at the end of this article for more details on using a voltage switch as charge controller.

The household wiring

A 12 volt system needs thicker wires than are used for regular house wiring for 120 volts or 250 volts. With a low voltage system, both the current and the length of the cable are important. If the wires are too thin, there will be too great a voltage drop, and with such a low voltage to start with there isn't much leeway.

Some solar catalogs publish tables on how to dimension the wires. The tables from Kansas Wind power were used for this house.

Regular 120 volt household wiring in the United States uses 12 gauge and 14 gauge wires. The thicker 10 gauge wires are the standard in this house.

Thicker wires are used for longer runs and for cables carrying more current. As heavy-gauge copper wires are more expensive, the layout of this system was optimized for using shorter runs that could use 10 gauge wires. The 10 gauge wires are the thickest size that fits directly into screw terminals for light fixtures and wall outlets. Thicker wires are simply more cumbersome to work with.

To optimize the wiring, a breaker panel was placed in the center of the house, with cables going out in all directions. These cables are all standard 10 gauge ROMEX wires, as the house is rather small (36 ft x 21 ft / 12 m x 7 m). The central breaker panel receives power through a 4-gauge cable from the main house panel in the utility closet on the side of the house (12 ft / 4 m away).

The main house panel has a large disconnect switch that disconnects both the positive and the negative wire from the outbuilding. This allows for a total separation in case there is a need to run a battery charger on the battery bank in the outbuilding, as it will stop transients from travelling into the house on either wire.

Breaker panel from Square D's QO series, which can be used for either AC or low-voltage DC electricity.

Main house breaker panel (top) and two-poled disconnect (bottom), which is located in utility closet on the side of the house.

From the disconnect switch, there is a 50 ft (16 m) long underground cable to the battery bank in the outbuilding. Heavy 2-gauge wire is used here, as a 12 volt current of 30 amps (360 watts) was assumed. In daily use, this cable rarely carries more than 120 watts (10 amps).

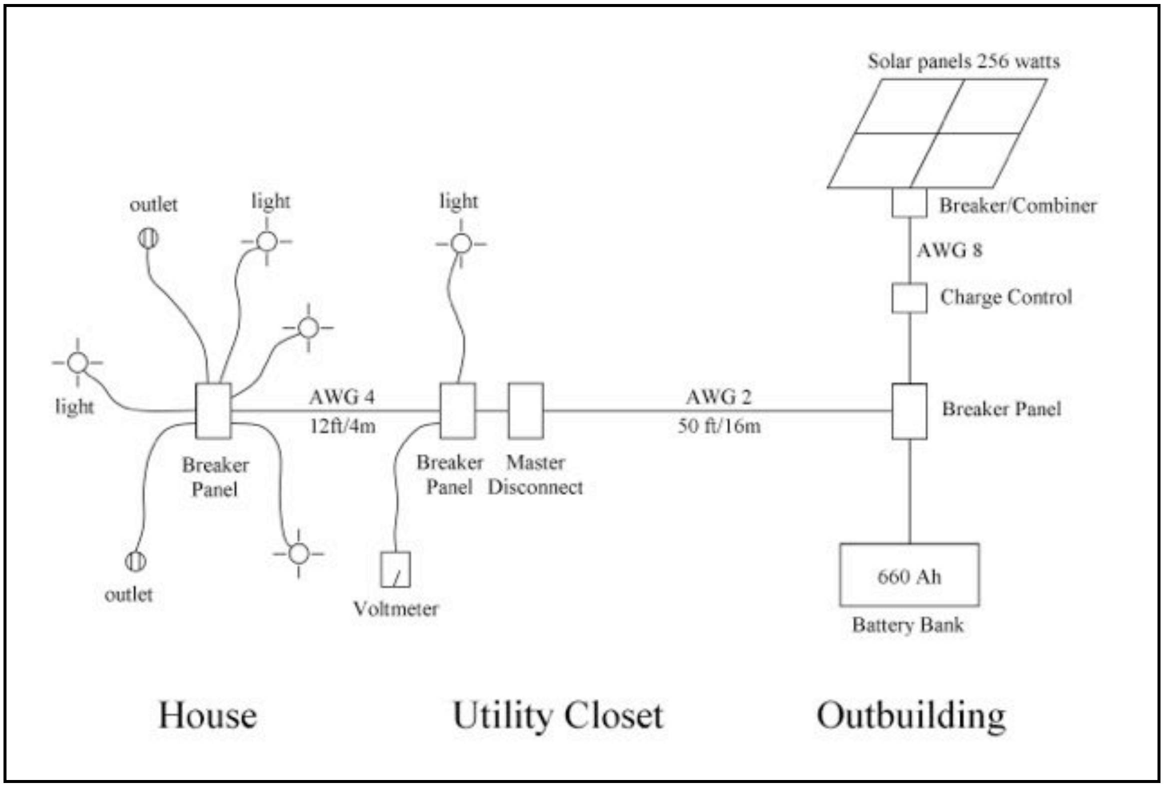


Diagram of main electrical system

The electrical system serving the two pumps is much simpler. The pumps are both located in the outbuilding, next to the breaker panel and battery. The circulation pump uses only about 1 amp, but runs 24 hours a day on a cloudy winter day. The booster pump uses about 10 amps, but only runs for a few minutes at a time.

The wires are hooked up according to the modern color scheme for DC electricity, i.e. black is plus and white is minus (this is different from the automotive standard of red and black wires).

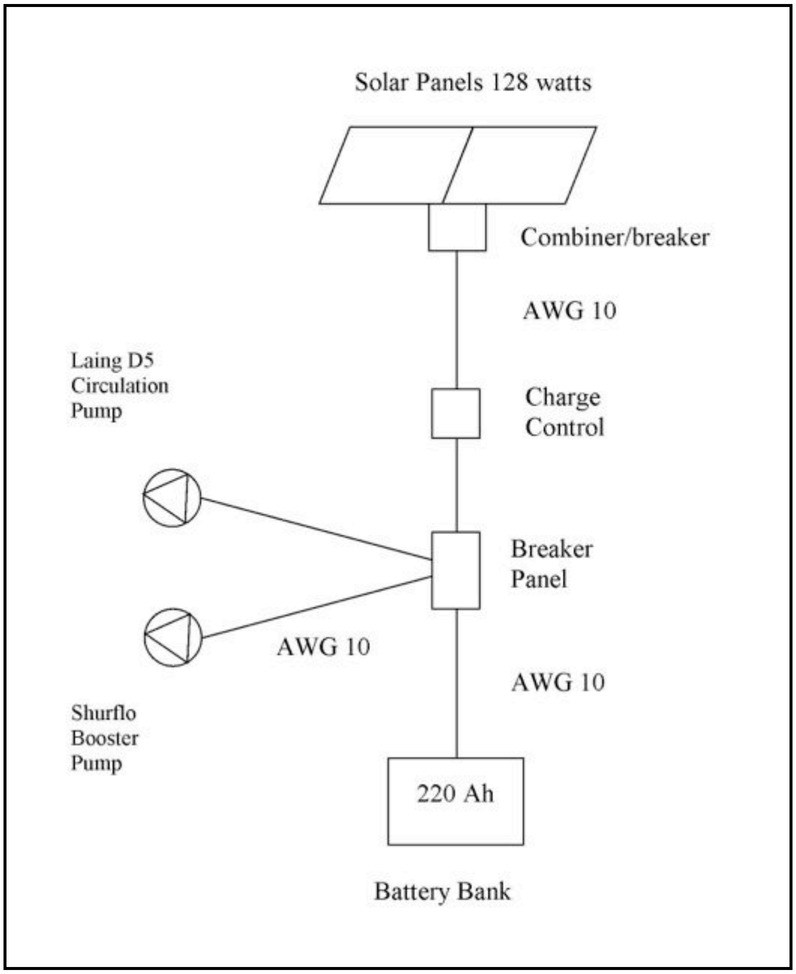


Diagram of secondary electrical system, which serves two pumps

Twisted wires

All the wires in the house are twisted. Twisted wires dramatically reduce the magnetic field around a wire and is standard practice in cables used for telephone and computer systems. Twisted wires do not reduce the electrical field, but with 12 volts, the field will be very low.

Most types of electronic equipment, such as chargers, computers, radios, televisions and DC motors produce transients and harmonics ("dirty electricity") which radiates off the household wires.

Light bulbs (incandescent, halogen, LED) do not generate dirty electricity, except for the types that have built-in electronics (fluorescents, CFLs, some LEDs).

The contractor twisting the wires, using a power drill.

The contractor twisted standard cables by cutting off the needed length, then put one end in the chuck of a power drill and slowly spun it. Care was taken to make sure the cable was not spun too tightly, as that would cause the insulation to become much thicker, possibly causing the wire to get hotter when carrying a high current. As the wires are thicker than normal, i.e. rated for a much higher max amperage, this should not be a problem, however.

Some wires happen to come pre-twisted inside the sleeve, and could be used instead. Some people have chosen this method. These are usually 3-conductor cables (i.e. 10/3), where the extra red wire is just not used.

Outlets

Special outlets are used to prevent anyone from accidentally plugging a regular 120 volt AC item into 12 volt power (and vice versa). Instead of the regular 120 volt outlets (receptacles), 250 volt/15 amp outlets were used for the 12 volt system. These fit in standard wall boxes and are wired the same as regular outlets, but the prongs are a little different.

12 volt light switches and outlet. The left prong is plus, the right is minus.

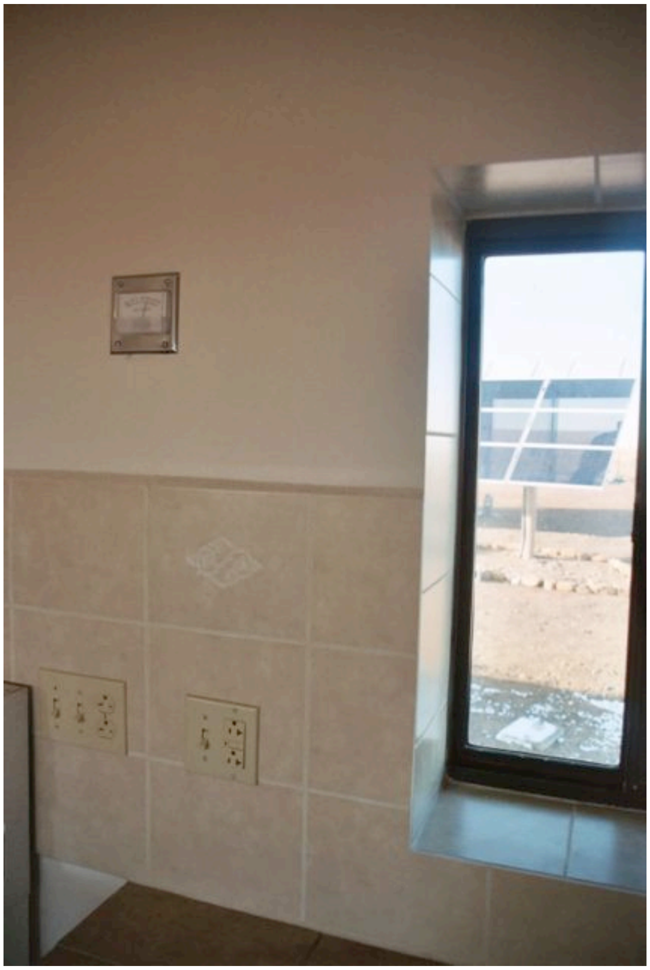
These outlets are not the kind used for stoves and clothes dryers, but most commonly used for window air conditioners. They are available from some hardware stores and solar catalogs. The building inspectors approved of this use.

Voltmeter

An analog (zero EMF) voltmeter is placed on the kitchen wall so it is easy to keep an eye on how the batteries are doing. With experience, it is also possible to catch problems, such as the need for equalizing the batteries.

The voltmeter is on a separate breaker on the main electrical panel for the house. This minimizes voltage drops that will give incorrect readings of the battery voltage.

There are more sophisticated electronic instruments available, but they are all computerized and emit dirty electricity and RF radiation.



Analog voltmeter on kitchen wall, where it is easy to glance at it.

Lights

The greatest use of electricity in this house is for lighting. The most lighting is used in the winter, when there is the least solar power available.

Much thought has been put into designing the lighting system to minimize the need for electricity. With solar, it is more cost effective to invest in more efficient lighting instead of spending more money on solar panels and batteries.

Three lighting technologies are used in this house: incandescent, halogen and LED. Those are the only technologies which do not emit EMF or dirty electricity (some LED types do).

LED lights are by far the most efficient, but also the most expensive and have the lowest quality of light. Some people with environmental sensitivities do not tolerate the light from LEDs.

Halogen lights are in the middle with cost and quality. They are the mainstay of this house. Incandescents are cheapest, but are wasteful of electricity.

The kitchen has three halogen lights and one LED light in the ceiling. One halogen light and the LED light are mounted above the sink. Most of the year, the LED light is just a supplement, but during dark winter storms it is used more to save electricity.

There are two lights in the ceiling in the bathroom. One is a 25 watt incandescent, which is controlled by a light switch beside the door. This is generally the only light used for bathroom visits. Some guests tend to forget to turn it off when they leave, but it's not a problem with a low-wattage bulb. A second ceiling light above the sink has a 52-watt incandescent bulb, which is controlled by a light switch away from the door, to discourage use. This lamp is only used when that much light is really needed.

LED and halogen lights above the kitchen sink. The LED is sometimes used as the only light during winter storms where electricity must be vigorously conserved.

There are two porch lights, which are both LEDs. They are used to access the propane refrigerator and the outdoor kitchen. It has happened several times that they have been accidentally left on all night, so it is good that they are the efficient LED lights.

Halogen lights are used in lamps that are on for hours every day, such as in the kitchen.

Incandescent lights are used where they are only on for short periods, such as in the closets and in seldom used ceiling lights.

Almost all light fixtures are the regular type, which can take ordinary 120 volt AC bulbs in the socket. This makes it easier to convert the house to AC some time in the distant future.

The house is designed for daylighting. This means that there is enough natural light in each room during a cloudy day that electric lights are not needed. This saves electricity when it is the most scarce. Natural light is also healthy. Some countries, such as Sweden and Denmark, have various sorts of daylighting requirements in their building codes.

Refrigerator

The refrigerator runs on propane. It has a little electric light inside, which normally runs on a 6 volt battery mounted on the backside, but this was connected to the household 12 volt system instead. The refrigerator is otherwise totally non-electric.

Gas refrigerators have a small flame, about the size of a pilot light. The amount of gas consumed is so small that gas refrigerators are normally placed inside people's houses, and vent their fumes to the inside, just as a gas stove does. However, this does not work where exceptional indoor air quality is needed, such as in this house.

To avoid the propane gas fumes, the fridge is placed in a little closet on the side of the house, with a sealed wall towards the rest of the house. This closet also houses the main breaker panel, a water pressure tank and two propane water heaters (for both water and in-floor heating), which are accessed through a separate door.

This refrigerator has the burner on the back side, with a short vertical exhaust pipe. A piece of 2¼" automotive exhaust pipe was mounted on the fridge to direct the flue gas to the outside. A slit was made to act as a backdraft damper so the wind doesn't blow out the flame.

The Diamond brand refrigerator/freezer is located in a closet on the side of the house. It is easily accessed from the kitchen via the covered porch.

The fridge is a Diamond-13 from Miller Refrigeration in Sears, Michigan, purchased through Dynamx in Chino Valley, Arizona. It has an overall volume of 13 cubic ft, of which about one third is for the freezer section. This model is not designed for RV use.

This fridge does not require any electricity to run. Some propane fridges have electronic controls that do require electricity. Their electronic components do radiate some and are best avoided. All modern RV fridges have electronic controls.

There are several 12 volt / 24 volt refrigerators and freezers available, but they all use DC motors which send out a lot of EMF and dirty electricity (more than AC motors). It was planned to later buy a 12 volt freezer and put it in the outbuilding and run it from the secondary solar system sometime in the future. That setup would keep the EMF and dirty electricity out of the main house. The freezer space in the propane refrigerator is sufficient, so the planned freezer was never purchased.

Washing machine

There are no 12 volt washing machines available. There are some non-electric washing devices available, but they have their limitations.

The purchased washer is a simple Whirlpool model, with no electronic controls. It is powered by the generator and works well. Some fancy models will not accept power from a generator.

The washer is placed in the outbuilding to keep the noise, fumes and EMF away. The outbuilding has a small (4 gallon / 15 liter) electric water heater, which is only used in the winter when the water from the storage tank is too cold to wash clothes well. This water heater is also powered by the generator. This setup works very well for the author. The small heater is not able to fill the washer with really hot water. If that was necessary, a larger water heater would be needed, but that would also increase the run-time of the generator before the washer can be started. An alternative is to then install a tankless water heater.

There is an outlet for an electric clothes dryer, which could be powered by the generator. No dryer has ever been installed. The author uses a clothesline and avoids washing clothes on rainy days or during winter cold spells. This works well in Arizona.

The generator

A propane powered generator is used to pump water from the well to a storage tank and for running the washing machine. This is done at the same time, about once a week. In the winter, it also powers the small 4 gallon / 1500 watt water heater for the washing machine.

The generator has also occasionally been used to power a 400 watt engine heater on the car, when it needs to be started on very cold winter mornings.

The generator is directly connected to the propane tank for the house. This tank is filled by a propane company truck, so there is no need for the homeowner to haul fuel for the generator. This makes propane a much safer and convenient fuel than gasoline and diesel. A propane generator is also almost smell free.

The generator has a rated capacity of 7500 watts. It can easily power the ¾ horse power well pump, washing machine, water heater and engine heater at the same time. A smaller generator would work.

The generator was chosen with a low rpm (1800 rpm) which means that it should last longer and produce less noise. This model is designed for RV use and is certified low-noise by the U.S. National Park Service.

The electricity from the generator is routed to the well and the outbuilding through a breaker panel next to the generator. The house does not receive power from the generator, as the generator power has a lot of harmonics (dirty electricity), which is bothersome to the author. Some generators have built-in inverters to prevent these harmonics, but then there will be high-frequency dirty electricity from the inverter instead.

Many off-grid houses use a generator to charge the batteries during dark winter days. This requires the use of a battery charger which is bothersome to sensitive people, even at a distance, as it dumps high-frequency transients on the household wiring. This house does not use a battery charger, but instead is extra-conserving of electricity the few days of the Arizona winter it is necessary.

The pumps

There are two pumps, which are both powered by the secondary 12 volt solar system.

The circulation pump is a LAING D5, which moves water around the in-floor hydronic heating system. It consumes about 10 watts, but will run 24 hours a day during winter storms where there is no sunshine to charge the batteries. On sunny winter days, it only runs at night, as the house is also passively solar heated.

The booster pump is a Shurflo 2088, which pressurizes the water from the well. It consumes about 100 watts, but only runs for a couple of minutes at a time.

See the separate articles about this house's heating and well systems for more details.

The Contractor

The author designed and sized the electrical system, but hired a handyman to do the installation. The handyman had never done a solar system before, but had no problems doing this one, with instruction. The wiring methods in the house were the same as for a regular AC system, except for the thicker wires. The solar system itself is different, of course, but not very complicated. The handyman built a similar system for himself a year later.

Planning for the future

A well-built house could last a century or more. Other people than the original owner will live in it. The original owner may use the house for other things than originally thought of. Sooner or later, the house will need to be sold to others. Some are sold much sooner than expected.

This author found that he used different outlets for different things, once living in the house for a few years. Some expected uses never happened, others never thought of did.

It makes sense to not tailor the electrical system too closely to what the owner expects to use it for, but to allow for future uses and that of others.

Skimping on the wiring and the number of outlets can backfire, as it is difficult, disruptive and expensive to later modify wiring inside the walls.

A low-voltage system only appeals to very few people. This house is designed so it later could be converted to regular AC power by either installing an inverter or connecting to the power grid (if it ever gets to the area).

All wiring is made to adhere to regular wiring standards. The breaker panel inside the house is listed for both AC and DC. There are electrical outlets for refrigerator, stove, washer, etc.

All light fixtures can be converted to AC. Most lamps would just need a new light bulb, while the LED lights are mounted onto standard circular boxes, so an AC lamp could easily be mounted instead.

Costs

The solar system itself (i.e. solar panels, rack, batteries, controller, breaker panels) cost about $4,000 in 2007. About $1,500 was paid for by the state and federal solar credits.

The thicker wires added a substantial cost to the construction, especially the thick cable between the buildings. This extra cost is not tabulated, but is somewhere above $1,000.

The propane refrigerator cost about $1,700.

The three LED lamps cost $75 to $105 each.

The generator cost $3,500, though cheaper models are available.

Total off-grid/12 volt cost was therefore about $11,000, in 2007. This cost is balanced out by the lower cost of the land and no expense for getting the grid extended to the house.

A comparable piece of land near a utility pole cost $30,000 more in 2006, when the lot was purchased. In 2013, the price difference is similar, for this area.

The cost of a grid connection varies with the distance to the nearest existing pole. In our area, with large lots, it presently [2013] costs a minimum of $5,000 and can easily be triple that.

In this case, going off the grid saved at least $20,000. That is probably a large reason why there are hundreds of off-grid houses in this area, and many more throughout the Southwest.

Living with 12 volt solar

The author has lived with the system for nearly five year as of this writing. He would do the very same system again if having to build a new house.

The system has worked flawlessly, with no power outages at all (quite unlike the nearest grid). There has never been a need to use the generator to charge the batteries, though power has had to be vigorously conserved during dark days of winter storms.

The six golf cart batteries in the main battery bank were replaced after four years. The best two of the batteries then became the secondary battery bank for the pumps, where they served well for an additional winter. During a March winter storm, these 4½ year old batteries started to fail. This was noticed because the water pressure pump sounded differently, when the voltage dipped below 12 volts. This was easily remedied by switching the pumps to the main battery bank and then replacing the batteries when convenient.

The off-grid lifestyle is not for everyone. All members of a household have to be ever-mindful of not wasting electricity, though it becomes routine. There is very little actual maintenance, which all could be done by a handyman, but a general understanding of the system is needed to live in an off-grid house, such as noticing that maintenance is needed.

Absent-minded people may have difficulties. Guests do forget to turn off unused lights, especially in the bathroom. During a week-long absence in a period with full sunshine every day, a friend stayed in the house by himself. After that, the batteries seemed a bit stressed, as if they'd been overtaxed (fixed by equalization).

For more information

More information about off-grid low-voltage systems, maintenance, appliances and resources is available on www.eiwellspring.org/offgrid.html.

Spring 2013