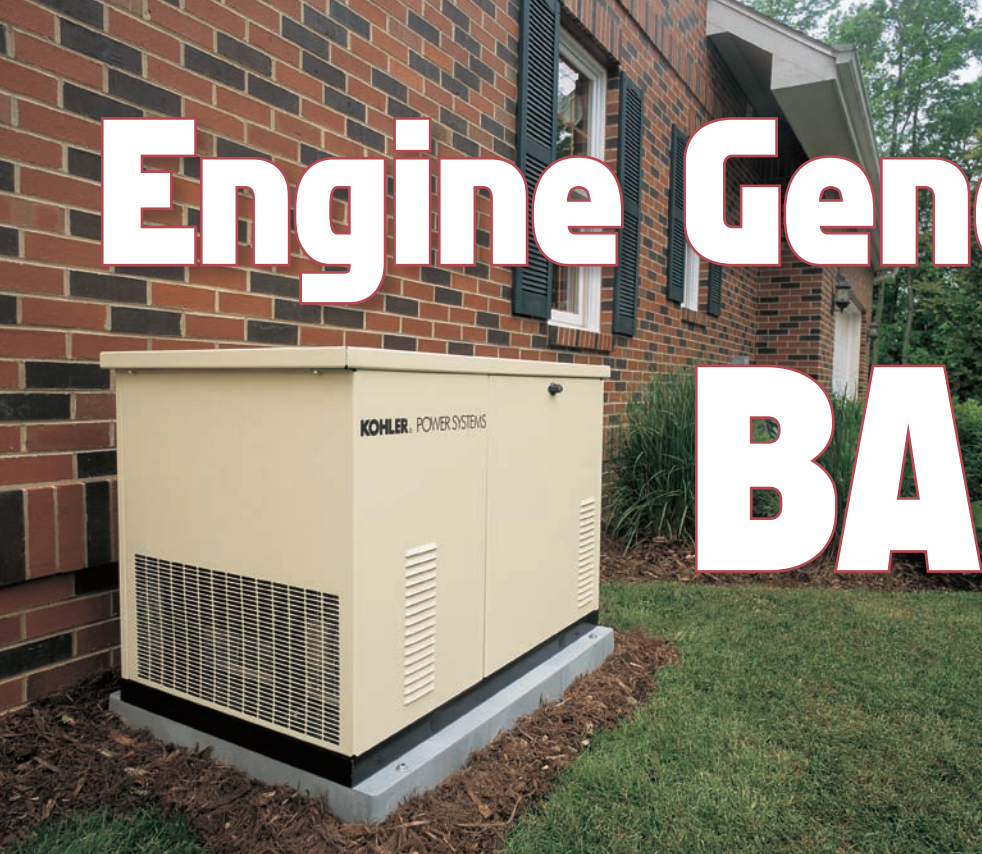


Engine Generator BASICS



Courtesy www.kohlerpower.com

by Allan Sindelar

Unless you have a good hydro or dependable wind source, or an excessively large PV system, sometimes the only way to keep your off-grid power system operating is by using an engine generator. But many residential generators are poorly matched to the job, since the selection and purchase of a generator is often an afterthought. The result is the generator becoming the weak link in the system, with inefficient, unreliable performance, rather than being an integral component of a well-functioning system. Here's how to analyze your generator needs and choose the right unit for the job.

Function & Purpose

Generators serve three main roles in off-grid home systems:

- The first is **backup charging**, where the generator makes up for any deficit in energy from the solar array or wind turbine, since the generator will work in any weather.
- The second function is **battery equalizing**. All flooded batteries need to be overcharged several times each year for best service life and performance. Equalizing is the deliberate overcharge of an already-full battery—raising the battery voltage to a higher-than-normal voltage (as specified by the battery manufacturer) and keeping it there for 2 to 3 hours. A minimum charge rate of about C/20 is necessary to overcome internal resistance to achieving such a high voltage (see “C-Rating” sidebar). Most off-grid PV arrays aren't powerful enough to accomplish this, especially during the winter, so a generator becomes an essential tool to achieve this.
- The third role is to **run specific loads that exceed the capacity of the inverter(s)**, such as 240-volt deep-well pumps, stationary shop tools, and even air conditioners.

The Basics

“You get what you pay for” might as well have been coined by a generator owner. Even in a well-designed off-grid power system, the generator is likely to be the single greatest source of maintenance and aggravation. It's a mechanical device, rather than electrical, so it requires regular maintenance and *will* eventually break down—usually when it's most needed.

Ask yourself: Is a breakdown just an annoyance or will it completely disable my home's power system? The more serious the consequences of the inevitable breakdown, the greater the appeal of a top-quality commercial/industrial generator. Consider also that unless you are prepared to maintain and repair the machine yourself, you will need reliable local support when the eventual failure occurs. An investment in quality quickly pays off.

Generators for home use may be purchased for as little as \$300 or as much as \$12,000. The least-expensive units are designed for occasional homeowner use with power tools or

The rated output of this generator is the combined wattage of both 120 V legs. At most, half of that power is available at 120 V—full power is only available at 240 V.



Courtesy www.positiveenergysolar.com

C-Rating

The term *C-rate* refers to the rate of charge or discharge of any battery, expressed in relation to the battery's capacity. A C/10 rate on a 220 amp-hour battery string would be 22 amps ($220 \div 10$); a C/20 rate would be 11 A ($220 \div 20$). For long service, batteries must be charged at a C-rate sufficient to overcome internal resistance under varied conditions and age. As a general rule, flooded lead-acid batteries need at least a C/20 rate to charge and equalize properly. A C/7 charge rate is about the highest that these batteries can tolerate.

cement mixers, for instance. "Contractor's specials," common at home-improvement centers, are just that—with their low initial cost, they are designed to provide temporary power until utilities are installed or to build a remote cabin. They're designed to be worked hard and then written off as a business expense when they die.

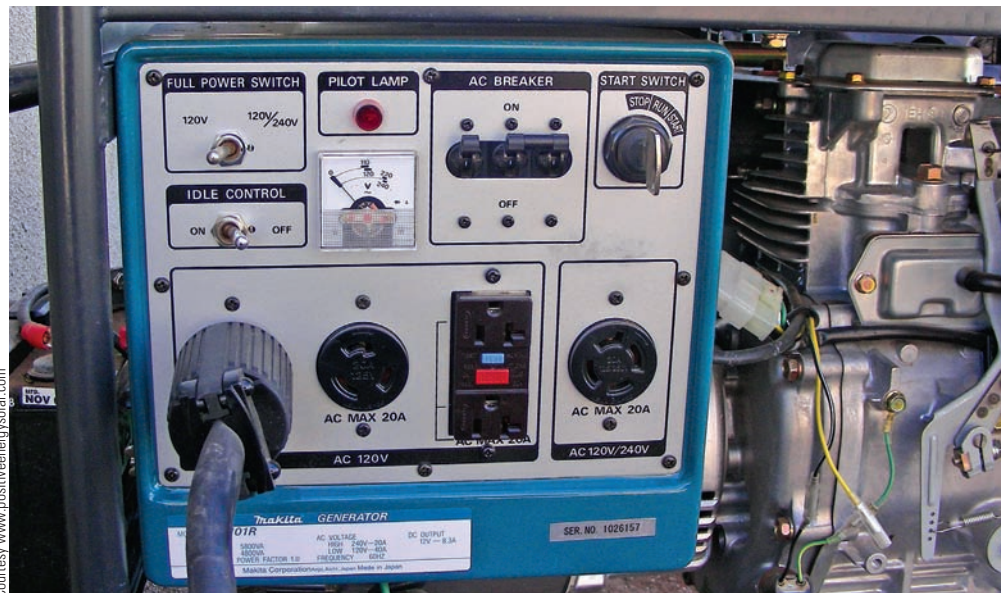
For off-grid backup, your choice will constitute a compromise between application, cost, availability, and support. But a higher-quality unit will generally have the following features:

- **Electric start with two-wire remote start capability:** "Two-wire" means all starting control functions (such as cranking and crank duration) are handled within the generator, rather than externally. Remote start capability means that the start and stop signals can be sent from an inverter or other controller. (See "Automatic Generator Start" sidebar.)
- **No or minimal standby load:** Some generators, designed primarily for on-grid standby use, draw energy—even when not running—for control functions, charging the starter battery, and even for block-heating in cold climates. This may be acceptable for use with utility power, but not for off-grid systems. Look for a generator that has no parasitic draw when off, or expect to add a separate small PV module and charge controller to keep the starting battery charged.
- **Engine speed:** In general, quality conventional generators run at lower speeds—typically 1,800 rpm versus 3,600 rpm—which directly translates into longer life. An 1,800 rpm unit will also operate more quietly, with less vibration and lower fuel usage.
- **Onboard starting battery charging** when the engine is running. Generators designed for on-grid "residential standby" operation sometimes require an external battery charger.
- **Liquid cooling,** rather than air cooling. Liquid-cooled machines will run quieter and, being thermostatically controlled, will run at a more even temperature year-round, resulting in longer life.
- **Sound-attenuated housing** and a residential muffler for quiet operation.
- **Field-configurable voltage output,** unless the supply voltage matches your needs.
- **Floating or unbonded neutral-to-chassis connection.** Quality generators allow the neutral conductor to either connect to the generator chassis (for prime power application) or remain separate from

it. Portable generators are seldom properly grounded, so manufacturers ground the neutral output conductor to the chassis. When connected into a grounded power system, however, this presents a safety hazard, as the neutral is now bonded to the ground at two places—one in the power system AC (such as in the main AC service panel) and one in the generator—and the safety ground wire becomes current-carrying. Some units also include AC ground-fault protection, which is incompatible with connection to a grounded power system. There is no simple, code-compliant solution to this. The safest noncompliant approach is to bundle an insulated, green ground conductor with the power conductors between the generator and the main ground bus, which serves to ground the chassis and minimize shock potential.

- **A well-earned reputation for after-sale support** by the local dealer. Even the best generator will eventually need service and repair, often on-site.
- **A warranty of at least two years,** valid in off-grid applications.

Look for a generator that includes electric start and a panel switch that internally reconfigures the generation coils to provide full output at either 240 or 120 V—common on higher-quality portable generators.



Selecting Your Fuel

Generators are fueled by gasoline, propane (or its cousin, natural gas), diesel, or biodiesel. The least expensive generators and nearly all portable units use gasoline, which offers some advantages—mainly that gasoline is familiar and manageable by the unskilled user. However, it's highly flammable, and fuel storage will need to be a consideration. Allowed to sit in a generator's fuel tank, gasoline will eventually deteriorate, leading to clogged orifices and preventing the generator from starting when needed. Cold-starting also requires engaging a choke. Most auto-start generators are not gasoline-fueled for these reasons. A gasoline generator may be best suited to applications where it is only used occasionally and the gasoline is drained (or run out) after each use.

LP gas (propane) is commonly used in higher-quality stationary generators. Many off-grid homes already have an LP tank and lines for cooking and heating, so the fuel is convenient and relatively safe. Propane has an almost unlimited storage lifespan. LP generators will generally start reliably down to about 10°F. Natural gas and propane burn cleaner than gasoline and diesel, and wear on internal engine parts is reduced.

With some notable exceptions, diesel generators are typically long-lived and high-quality—and relatively expensive. However, the fuel is best suited to warmer climates, as it gels below freezing temperatures. The drawback to diesel fuel is that, compared to natural gas or propane, it's a "dirtier" fuel, producing more pollution. Fuel storage requires extra care against spills and leaks, and may even be regulated. For the eco-tinkerer, diesel units may also be run on biodiesel or either virgin or waste vegetable oil, taking the appeal of "living on renewable energy" to a greater level. Vegetable-based fuels don't generally need additives to prevent gelling; the fuel is heated instead.

Automatic Generator Start

Autostart generators are capable of remote start, meaning that these units can be started by an external signal, such as one that might come from an inverter when it detects a set battery voltage level. The control over the generator's operation—that is, when to run and when to stop—is external to the generator, while the generator provides its own safety protection, such as shutoff for low oil level, overheating, and other factors.

Among remote-start generators, the simplest is the "two-wire start," in which a closed contact tells the generator to start and run. When the contacts open, the generator stops. All inverters with generator-start capability can control the generator in this method, as can other system components such as a manual switch, a voltage-controlled relay, a threshold signal in some system monitors, and even a signal triggered by a big load.

Automatic generator operation is at best a mixed blessing. In theory, the inverter calls for the generator to provide backup charging power whenever the RE source proves insufficient.



3 Courtesy www.positiveenergysolar.com

This Onan RS20000, 20 kW LP generator is a perfect match for four OutBack VFX3648 inverters (see photo at right).

Sizing a Generator

As a general rule, a generator should be able to supply the full charging capacity of your inverter, plus loads that typically run while charging and provide some reserve capacity. This both minimizes runtime and maximizes C-rate—the charge rate necessary for good battery care. Generators used in home systems will vary between about 2,500 watts and 20 kilowatts of continuous rated power.

Often, a generator is purchased before the power system is designed, as an early source of power for construction and water supply. The result is that the RE system designer must take the existing generator and adapt the system design to best use it—a backward approach to system design. A better plan is to consider a generator as part of the overall power system design. The preferred approach to sizing a generator starts with the battery bank.

However, numerous real-world bugs can interfere with such seamless operation. Automatic operation can lead to a system owner failing to perform regular maintenance, and neglecting something as simple as checking oil levels can cause unintended problems that aren't noticed until the entire system shuts down. Poor programming can lead to excessive runtime and fuel consumption, yet not guarantee that batteries are adequately charged.

The most likely path to eventual failure is total dependence on a generator in an unattended system. "Auto-generator start systems built into all of the inverter systems should be viewed as a convenience device," cautions Christopher Freitas of OutBack Power Systems, "not as a comprehensive, 'bullet-proof system' which will operate 100% of the time."

Longtime installer Todd Cory is more blunt: "I *never* configure autostart generators. Having a machine automatically start/stop while unattended is at best a recipe for damage to gear and, at worst, a fire that could destroy the entire homestead."

Generator Sizing



This large home system uses four OutBack charger/inverters in a 120/240 output configuration. The middle two inverters are mainly used to achieve a C/13 charge rate for 2,200 Ah of batteries at 48 V.

Most PV arrays for off-grid homes will be sized to meet or exceed design loads for part of the year. This seasonal duration may cover all except the heart of winter in the sunny Southwest, or may only cover half of the year in northern climes. Battery banks are typically sized to provide two to four days of autonomy (time the batteries can supply energy without further charging), depending on the seasonal climate and other factors.

Because arrays and batteries are sized to different purposes, the array is seldom large enough to meet even the minimum C-rate needed to routinely fully charge and regularly overcharge (equalize) the battery bank. Hence

Some inverter/chargers, like this Magnum MS4448AE, can accept either 120 or 240 VAC output from a generator.



The example we'll use is an 1,800-watt PV system installed at an off-grid home in the Midwest. The battery bank is two strings of flooded lead-acid batteries, with eight 6 V batteries in each series string. The battery bank is rated at 700 amp-hours at 48 VDC nominal—or about 60 V under charge.

The *minimum* charge rate, C/20, is 35 A ($700 \text{ Ah} \div 20$), but the 1,800 W PV array will produce 30 A at best ($1,800 \text{ W} \div 60 \text{ V}$)—less than desired. With cloudier weather, the generator and inverter become even more important to achieve the desired charge rate. An ideal charge rate would be about C/10, or 70 amps. This will minimize generator run time, while still allowing the PV array to contribute 25–30 amps when it can without exceeding the batteries' maximum charge rate.

We would like a charger, usually integrated into the inverter, that can hold a 70 A charge rate. Sticking to the most commonly used inverter/chargers, the Xantrex XW4548 is rated at 85 A, which is plenty. The Magnum MS4448AE puts out 60 A, which is close enough for our needs. The largest OutBack VFX3648 is rated at 45 A, so one solution would be a pair of FX3048Ts, each rated at 35 A DC, for our desired 70 A total. Let's assume the Xantrex XW4548 inverter for this example. According to the manufacturer, the AC input charging current necessary for this inverter to create the full charge rate is 24.8 A at 240 VAC, or 5,950 W. This gives us a starting place for sizing a generator to power this inverter.

First, adjust for maximum load. As a rule, most generators run best close to, but not at, maximum output. 85% is a commonly used figure, although some high-quality units can be run at 100% of their nameplate rating. So $5,950 \text{ W} \div 85\% = 7,000 \text{ W}$, assuming a quality, accurately rated generator. Next, adjust for elevation and temperature. Assuming sea level, adjusting for elevation is not necessary (see "Elevation & Temperature Effects" below). To adjust for temperature, assume 100°F operation, which is an approximate derate of 6% for a generator rated at 60°F. This results in $7,000 \text{ W} \div 94\% = 7,447 \text{ W}$ —a 7,500 W generator should be sufficient. If there are loads that will be run while charging the battery, apply the temperature and elevation adjustments to them and then add this amount to the sizing total.

Finally, make sure the voltage output of the generator matches the input of the inverter/charger. Traditionally, off-grid inverters have been based on 120 VAC input and output. In this example, matching the inverter's input voltage to the generator's output is no problem since this inverter/charger supports both 120 and 240 V configurations.

Elevation & Temperature Effects. Power output of all generators is rated for use at sea level. As elevation above sea level increases, air becomes thinner, with less oxygen. The result is decreased performance. Most generator owner's manuals include an adjustment factor, but a general rule is to derate 3.5% per 1,000 feet above sea level. For example, at 5,000 feet, a generator will produce about 82% of its rated output.

As the ambient air temperature increases, the engine and alternator heat up, which decreases both efficiency and power output. Generator manufacturers will rate power output as low as 60°F and as high as 120°F; there is no common standard. Using both rated output power and temperature as starting points, a typical deration is 1.5% per 10°F above rated temperature. For example, a generator with a rated output of 10,000 W at 60°F will be capable of 9,400 W at 100°F.

Modified-Square-Wave Inverters

Most modern off-grid PV systems use sine-wave inverters. But plenty of older modified-square-wave inverters—what are still euphemistically marketed as “modified-sine-wave” inverters—remain in use today. The most common are the Xantrex (Trace) DR and earlier U-series, and most RV and marine inverters.

These inverters have special generator requirements. While modern inverters use the entire power waveform (the technical term is “power-factor-corrected”), older modified-square-wave inverters use only the voltage peak of each wave. What this means is that the generator must maintain full peak voltage under a charging load.

High-quality generators are able to maintain peak voltage (the ideal is 164 to 170 V on a 120 V wave) under load. But cheaper generators tend to have a flat voltage waveform—that is, the measured RMS voltage may be accurate, but the peak is lower than 164 V under load. This is adequate for occasional power tool use, but can result in very low charging current—the familiar mystery of low-DC charging current from a well-running generator.

Three possible solutions address this problem. The first is to oversize the generator, so that it is lightly loaded while charging. Second is to increase engine speed, which works in some generator-inverter combinations by increasing voltage proportionally. The best solution is to use a modern inverter-generator. These units maintain full peak voltage up through their maximum load and, if sized correctly, will enable a modified-square-wave inverter to charge at its full capacity. Most inverter-generators have 120 VAC output, which is ideal for a single-inverter power system.

the need for the generator, which can add the necessary charge current to get this done, and may be even the only contributing charging source during winter—so it should be sized to handle the job.

AC Voltages

Typical utility power is split-phase 120/240 VAC. If you look inside a home’s electrical distribution panel, you will see three non-ground wires coming in: two “hot” conductors and one “neutral” conductor. The voltage between each hot and the neutral conductor is 120 V, and the voltage between the two hot legs is 240 V. Most off-grid homes have only one hot conductor, and operate at 120 V.

An off-grid system’s generator must be matched to the voltage needs of the inverter/charger. Generators provide AC output in one of four ways:

- **120/240 V with full-rated power only available at 240 V.** Most inexpensive, homeowner-grade generators are set up this way. The rated output is the combined wattage of both 120 V legs, and at most, half of the rated output is available at 120 V.

- **120/240 V with a switch** that internally reconfigures the power generation coils to provide full output at 120 V when desired. This is a valuable feature and is fairly common on higher-quality portable generators.
- **Straight 120 V:** Many of the newer “inverter-generators” (see below), and most models designed for RVs, put out power only at 120 V. Small, portable units (less than 2,000 watts, generally too small to use effectively as charging sources) are only 120 V.
- **Field-reconfigurable:** Most top-quality generators may be reconfigured to offer either full-output 120 V or 120/240 V by changing the connections of the output wires inside the generator. This task is best handled by a generator service technician or skilled RE installer.

Most inverters manufactured since the late 1980s can only receive 120 V input from a generator. For most off-grid homes, this is not a problem, since 240 V loads are typically large bulk loads from water heaters, clothes dryers or electric ranges that are inappropriate in an off-grid home. With the exception of AC well pumps, off-grid homes are unlikely to have 240 V loads.

When a typical 120/240 V generator that is not capable of full output at 120 V is paired with a 120 V inverter, two problems occur. First, a 120/240 VAC generator is only capable of half of its rated output when connected to the input of a 120 V-only inverter. Second, the load on the generator is unbalanced, with one 120 V leg fully loaded and the other unloaded. This imbalance can lead to premature generator failure.

This means that the less-expensive generators are least able to efficiently back up the most common inverters. For example, a low-cost generator may be specified at 5,500 W maximum output. But the usable “rated” output is not “maximum” output. Similar to the way an inverter’s continuous-duty capacity is compared to its capacity to meet larger surges, “rated” output is the level of power a generator can deliver continuously. Usually, it’s about 85% of the “maximum” power, although some lower-quality generators



Inverter-generators, like this Honda EU6500iS, can adjust engine rpm to meet loads while an onboard inverter keeps the output waveform on spec.

Courtesy: www.hondapowerequipment.com

Generators in Grid-Tied Systems

Batteryless grid-tied PV systems are in many ways the essence of simplicity. Reliable and essentially maintenance-free if skillfully installed, they are ideally suited to homes accustomed to utility power. But the chief limitation to batteryless PV systems is lack of backup power during utility outages. If you want backup power for “critical” loads, such as refrigeration or lighting, there are three common approaches.

The first approach is to **install a battery-based grid-tied system**. While a battery backup system works well if designed and installed well, it will add cost and complexity to the system. It will be slightly less efficient than a batteryless system, as it must balance AC production with charging and maintaining batteries, rather than solely maximizing AC production into the grid. It also will usually supply only enough stored power to support selected house loads during a typical short-duration utility outage, though RE-generated energy will extend the length. Off-the-shelf packages are available to support a modest load profile during an outage of short duration: A typical battery bank of four 100 amp-hour sealed batteries only provides 4 kilowatt-hours of usable power before it must be recharged; this would be a hard limit for most households at night or during a snowstorm.

Adding a generator to a battery-based grid-tied PV system will extend the system’s backup duration indefinitely—until the fuel runs out or the residents get tired of the noise. With good design and execution, this approach can work well. However, the system quickly reaches complexity beyond the skills of most homeowners and novice installers. It must be set up and programmed to work reliably and automatically, and must be tested and exercised regularly if it’s to be relied upon. Plus, not all manufacturers’ equipment is capable of integrating both generator and grid inputs—Xantrex’s XW system will; OutBack’s will not.



Courtesy www.kohlerpower.com

The third approach is to **install a generator and transfer switch** as a backup source during outages without tying the systems together. The disadvantage is that switchover to the backup source is not instantaneous, and with batteries eliminated, the generator must run continuously whenever backup power is needed. Advantages include the simplicity of separate, conventional systems, each supported as necessary by its separate provider and each optimized to a single task. An entire market has developed for generators for residential standby use.

All three approaches are considerably more costly than batteryless systems, for two main reasons. The first is simply the added hardware and complexity. The second is the cost of modifications to a home’s wiring. Since none of these approaches typically has the capacity to run an entire home, key loads are identified as critical to operate during an outage. These usually include some lights, a heating source, refrigerator and freezer, and communications (computer, television, and Internet). Key circuits must be identified and moved from the home’s main breaker panel to a “critical loads” panel to be fed by the backup source. Unless specifically planned during the home’s original construction, this is a labor-intensive job for an experienced electrician.

If a grid outage is no more than an inconvenience, install a batteryless system and enjoy the occasional meal by candlelight when the grid goes down. If power during an outage is critical and typical outages are infrequent and of short duration, a grid-tied system with battery backup is a good choice. If an outage would be potentially catastrophic, such as a winter ice storm that can cause power to be lost for days in subfreezing weather, the battery and PV recharge capacity of a battery-based grid-tied system will be insufficient, and a backup generator will be a wiser choice. Consult with a reputable local RE installer or generator dealer to determine the best approach for your needs.

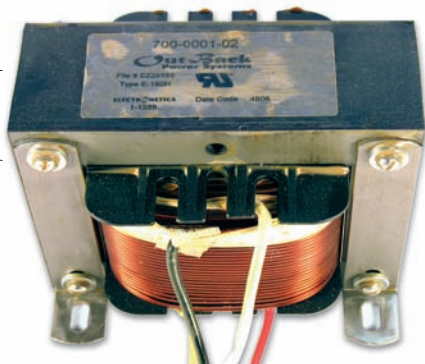
are not even capable of their “rated” capacity. How much power is really available? First, check the rating carefully: the 5,500 W rating is likely to be around 4,700 W in continuous duty, such as battery charging through an inverter. Second, the continuous rated power is available only at 240 V, so a single 120 V inverter can only access half of this output capacity, or 2,350 W.

One solution is to use a balancing autotransformer to step down the 240 volts to 120 V before sending it to the inverter. This allows the full power and both 120 V legs to work in balance. However, a typical autotransformer for this purpose retails for more than \$500, making the “low-priced” generator much more expensive.

Another solution, usually practical only in larger systems, is to use a stacked pair of inverters to both receive and produce 120/240 V power. This is a common approach with OutBack inverters. A few modern off-grid inverters, including Magnum’s AE series, Xantrex’s XW, and Apollo’s TrueSineWave are configured as 120/240 V split-phase units. These units are able to use both 120 V legs of a generator to provide balanced charging from both hot legs. The new Silent Power SP4024 inverter can use either 120 or 240 V input. No step-down transformer is needed with any of these inverters.

Another option is to select an inverter-generator, a relatively recent development. The inverter (which cannot substitute for the RE system’s inverter) is an integral part of

Courtesy www.outbackpower.com



An autotransformer can convert 240 V output from a generator to 120 V needed by an inverter's charger.

the generator, electronically synthesizing the voltage, current, and waveform, while maintaining full-peak voltage up through their maximum load. As the 60-hertz AC waveform is not dependent on engine speed, the engine speed varies according to the load. This allows an accurate pure-sine waveform, while reducing fuel consumption and noise.

Recommendations

Generator models are rapidly evolving, with new models entering the market and old favorites being discontinued. Most of the reliable, small generators of years past were made obsolete by California's emissions standards and changing markets. Newer models have been developed primarily for the on-grid home standby market, rather than for stand-alone use. Standby models, intended for

Maintenance, Safety Features & Warranties

On most generators, maintenance is necessary but not difficult. Every generator includes an owner's manual with a maintenance schedule and instructions. Typical maintenance includes checking and changing oil, fuel filters, and air filters. Less-frequent maintenance includes adjusting valves and changing spark plugs and coolant.

Nearly all generators include an automatic shutoff switch, which activates if the oil level drops too low. Additional safety features designed to protect the generator are included on better quality units. These may include overtemperature/overload, overcrank (cranking an already-running engine), and over/under voltage and frequency. Some units use a digital controller capable of alerting about a variety of faults.

As you select your generator, be sure to read the fine print of the warranty. The best standard warranties I have seen are for a period of two or more years (with extensions available at extra cost), cover parts and labor, do not exclude off-grid applications, and are transferable. A few include on-site service. Some warranties are voided if gasoline engines are converted to LPG while others allow the aftermarket conversion.

backup power during utility outages, are marketed as low-maintenance home appliances. They will commonly require utility power to maintain controls and charge the starting battery, and even for running block and intake heaters in cold weather—all unacceptable loads in off-grid use. In addition, fierce competition in this market has encouraged an emphasis on low price over high quality. There is a clear and unmet need for simple, reliable, commercial-grade generators not designed for the residential standby market.

The safest bet is to buy a well-respected brand, or at least a generator that comes with a brand-name engine—it will be much easier to find parts and service for a well-established brand than for some no-name model. Finding a high-quality used machine with low hours and evidence of proper care may also be a possibility. Consider also an inverter-generator, as these are gaining wide acceptance, with sizes available up to 6.5 kW. Honda, Yamaha, Robin, and Cummins make high-quality inverter-generators. All run on gasoline, but some of these brands may be converted to LP gas without voiding manufacturers' warranties.

Among conventional portable units 6 kW or less, Honda's EM or EB, and Yamaha's EF and YG series have been well regarded for years. Multi-Quip and Robin—made by Fuji Heavy Industries and marketed under the Subaru, Makita, and Baldor names—also have solid reputations.

In higher-quality commercial units, Kohler's 10ERG is a well-regarded model developed for the RV market and adaptable for off-grid use. Onan makes several adaptable units, including the RV QG 6500LP, RS 12000, and RS 20000 LP, the latter two suited to larger systems. There are some nice Onan diesel inverter/generators (the HQD series) up to 18 kW.

Notable negative comments have generally been directed at the cheapest generators, with poor waveforms, inflated output claims, and lack of long-term reliability. Also, avoid knockoffs of well-known models, especially low-cost inverter-generators now on the market. Reliability is unknown, and repair parts may be unavailable.

Access

A PV system installer since 1988, Allan Sindelar (allan@positiveenergysolar.com) founded Positive Energy Inc. of Santa Fe, New Mexico, in 1997. He is a licensed commercial journeyman electrician and a NABCEP-certified PV installer.

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