INVERTER *basics*

The best type of inverter for your application is the one that meets the system's requirements and results in the highest performance for the lowest cost, while operating reliably. Here's how to make the best match.

by Christopher Freitas

Renewable energy system designers and installers often say that the inverter is the brains of an RE system. But I've always thought of it more as the system's stomach: It digests the energy provided by the PV modules or batteries into something that is more useful and better regulated.

The main function of an inverter is to convert direct current (DC) into alternating current (AC), and to change the voltage level into a stable 120 or 240 VAC that can be used by household appliances or "sold back" to the utility grid.

The word "inverter" was originally used because the output wave form produced by its circuits alternates between a positive and a negative voltage. This device "inverts" the polarity of the power source (typically, a battery or PV array), causing the current to flow in alternating directions through the load. Hence the term "alternating current."

Inverters have a wide variety of designs, capabilities, and features. Understanding their differences can be as simple as dividing them into two groups based on their cost.

Inexpensive Battery-Based Inverters

Low-priced inverters (less than $500) are available from auto parts and large retail stores, as well the Internet. The smaller ones (less than 400 watts) plug into an automobile's cigarette lighter jack, while the larger ones (500 to 3,000 W) require a connection wired to a battery. (For safety reasons, this connection should be fused, but often this is not mentioned in the sparse instructions provided.) These inverters usually have very few safety or protection systems and are not listed to any UL standard. Usually, only short-term warranties apply and no customer support is available.

Low-cost inverters are for small electronic loads, such as small TVs and laptop computers. Although some of the higher-power models can power hand tools, the quality of the output power while the tool is operating may damage other more sensitive loads that are also connected. Some AC loads, such as some chargers for rechargeable battery packs, as well as the batteries themselves, can be damaged by the poor AC output wave form and poor voltage regulation, since they do not produce a true sine wave output (see "AC Output Wave Forms" sidebar for more information).

Most inexpensive inverters lack isolation between the DC input and the AC output. Typically, the DC negative is directly connected to the AC neutral. This allows them to be smaller, lighter, and cheaper to manufacture. This can, however, be a hazard when trying to install them in a *National Electrical Code*-compliant manner or if used with ground-fault circuit interrupter (GFCI)-protected AC outlet circuits.

Inexpensive inverters should not be used for residential or commercial systems, which need to meet the requirements of the *NEC* and/or be inspected. These inverters also cannot be grid-tied as they do not include the necessary synchronization capability or the protection systems required by utilities to protect utility line-workers and homes. Their limited safety systems also mean that they should only be used with continuous supervision, in case a problem with the inverter or a load occurs.

Exeltech's XP line provides a super-clean wave form appropriate for sensitive electronics.

Courtesy www.exeltech.com

Many inexpensive inverters boast power ratings that are not based on a continuous operation or real-world conditions. These power ratings may make some appear to be a better deal, but disappointing performance often occurs. To ensure acceptable operation and reliability, choose one with a power rating twice as large as your application requires. The low efficiency (often less than 80%) of most of the cheaper inverters can result in lower overall system performance—requiring additional, expensive PV modules—resulting in higher overall system costs.

Expensive Inverters

More expensive inverters (more than $1,000) are designed to operate in an efficient and safe manner continuously, even under less-than-ideal conditions. These inverters are designed for permanent installation and are compliant with both *NEC* and UL requirements. Because they include more protective and safety systems, they are larger and heavier than inexpensive inverters. They are well worth the extra cost when the application requires an efficient, reliable, and safe source of AC power.

Expensive inverters almost always include DC-to-AC isolation, which meets *NEC* and UL requirements and allows them to be used with GFCI circuits safely. They are also nearly all listed to one of the UL standards—either UL 1741 (for residential and commercial RE systems) or UL 458 (for RV and boat systems). Standards testing may be done by one of several nationally recognized testing laboratories such as UL, ETL, CSA, or TUV.

Expensive battery-based inverters often include additional features and capabilities, such as battery chargers, AC transfer switches, metering, load and generator control outputs, and even data logging and networking connectivity. Not all expensive inverters are the same—some produce smoother AC output wave forms, which makes them more suitable for powering sensitive loads such as electronics (TVs, computers, laser printers, etc.). Review the specifications carefully before selecting and purchasing one. Fortunately, the manufacturers of expensive inverters typically provide good user and installation manuals, as well as customer support and longer warranties.

Terminology

The term "inverter" is often confused with the word "converter," which is a more general term for a device that changes AC to DC (such as a battery charger), or a device that converts one DC voltage into another (DC-to-DC converter), allowing, for example, 12 VDC loads to operate on a 48 VDC battery system. Some modern inverters include both an inverter and a battery charger. Some even have 12 VDC output for operating relays or other devices—it's easy to see why people might be confused by the terminology.

OutBack's FX series is one of several inverter brands used for remote, battery-based applications.

Different Inverters for Different Applications

High-performance inverters are optimized for specific applications—there is no universal "one-size-fits-all" inverter. The range of inverter applications can be divided up into four categories:

- Off-grid
- Mobile
- Grid-tied with battery backup
- Batteryless grid-tied

It is important that the inverter you select is designed for the application for which it is being used. Otherwise, poor reliability and performance may occur and unsafe situations may result, which could damage the inverter or endanger the system's users or utility workers.

OFF-GRID. All off-grid inverters work with a battery bank that provides power, even when it is not sunny or windy. These inverters are typically able to work with multiple sources of power—solar, wind, hydro, and engine-generators—even at the same time.

AC wave form. Off-grid inverters are available with a variety of AC output wave forms. Today, most home and commercial power systems use sine wave inverters for sensitive loads. Many of the smaller systems (for cabins or other locations that do not have sensitive loads) still use modified square wave inverters since the cost is lower.

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AC OUTPUT WAVE FORMS

Lower-cost inverters produce a simpler square wave instead of the more complex sine wave. Some sine wave inverters have very visible, coarse steps making up the sine wave, while others have very smooth waves, by using hundreds of steps and more sophisticated AC output filtering.

The AC output wave form is also affected by the load being operated and the DC input voltage level. Many lower-cost inverters cannot regulate the AC output voltage when running more difficult loads such as motors, which can result in voltage spikes that may damage some appliances. More expensive sine wave inverters can operate nearly any load without problems and often have better power quality than a utility grid, since the utility distribution system can be affected by other AC loads operating in your neighborhood, resulting in power-quality issues.

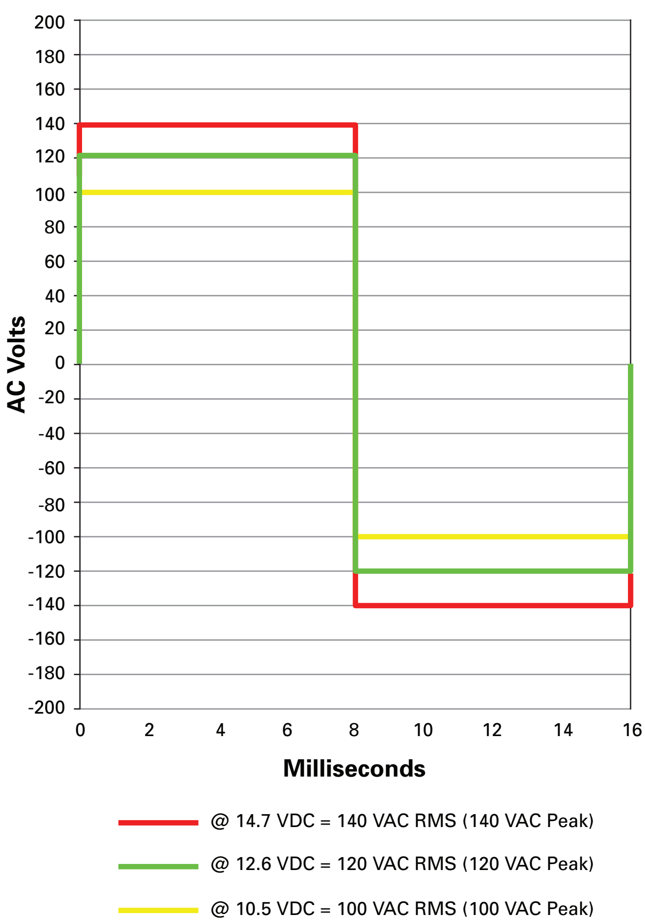
Square Wave Inverters. The easiest AC output wave form to make is a "square wave," in which the voltage alternates from positive 120 volts to negative 120 V, back and forth. This wave form has a lot of total harmonic distortion (THD) and results in poor operation of nearly all AC loads.

A square wave inverter cannot regulate its AC output voltage when the battery voltage changes significantly. They produce 120 VAC when the battery is at 12 VDC, but also produce 140 VAC when the battery is at 14 VDC and 100 VDC when the battery voltage is pulled down to 10 VDC, like during a motor startup. This can cause even simple AC loads like motors or lightbulbs to fail prematurely.

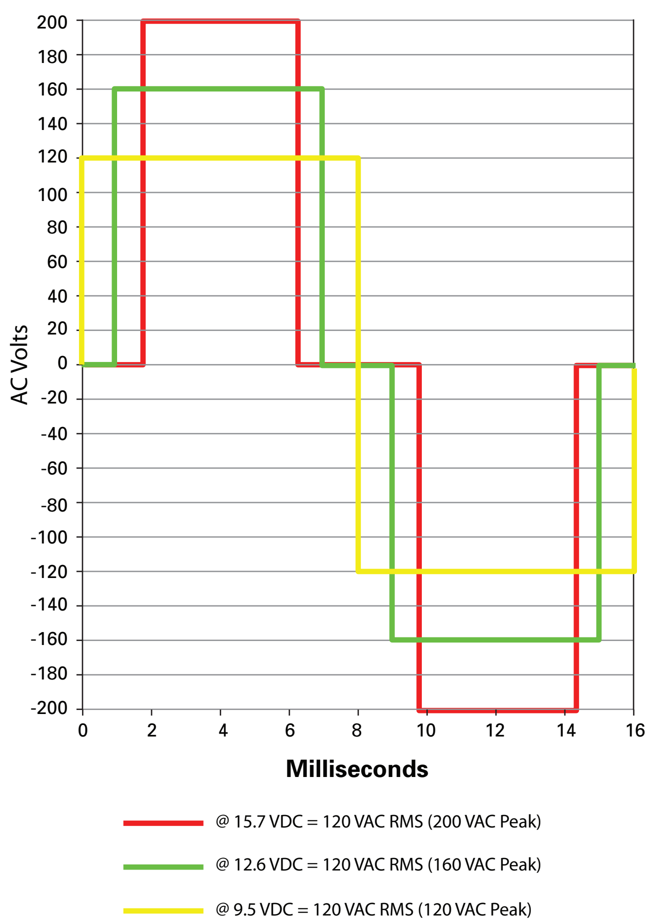
Because of these severe drawbacks, no square wave inverters are being manufactured today. They still do sometimes turn up used, but they are not worth considering, even if they are free.

Modified Square Wave Inverters. The addition of a small "off" time between the positive and negative pulse of the square wave significantly reduces the THD. And the shape of the wave form also can be controlled to allow regulation of the AC output voltage level as the battery's voltage changes. Modified-square pulses are tall and narrow when the battery voltage is high, but become short and wide when the battery voltage is low. This results in a consistent average voltage being supplied to the AC loads, and improves load

Square Wave Inverter AC Voltage at Low, Normal, and High DC Input Voltages



Modified Square Wave/Modified Sine Wave Inverter AC Voltage at Low, Normal, and High DC Input Voltages



compatibility and performance. However, more sensitive loads, such as variable speed motors on some hand tools and appliances, may still operate incorrectly, overheat, and be damaged from this type of wave form.

All of the inexpensive inverters and even some of the more expensive off-grid and mobile inverters produce this type of AC wave form. This wave form cannot be used for grid-tied inverters as the THD does not meet the utility requirements.

Modified Sine Wave Inverters. Although this term is commonly used, it is really a misnomer—there is no difference between a modified sine wave inverter and a modified square wave inverter, other than some sleight-of-hand marketing.

A **stepped sine wave inverter** produces another "in between" AC wave form. Instead of having a single positive or negative pulse punctuated by an "off" period between, a stepped sine wave inverter is able to produce a series of different voltage levels which can be arranged to produce what is often described as a "Mayan temple" shape. The number of steps varies as the battery voltage changes. At higher battery voltages, there are fewer, but taller steps; at lower battery voltages, there are many shorter steps.

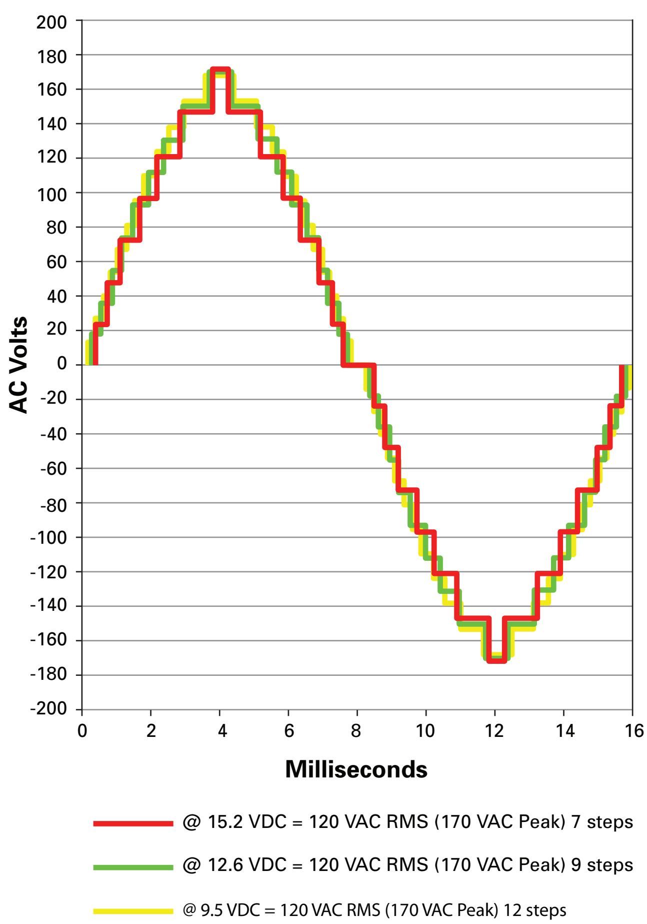
This approach produces a wave form with a much lower THD than a modified square wave inverter and offers good performance and DC-to-AC conversion efficiencies of more than 90%. Some of these inverters are even able to be grid-tied since the THD is low enough to meet UL and utility requirements.

True sine wave inverters produce a wave form that closely matches what is provided by a utility grid. Some of them are able to provide AC power that is better regulated and even has lower THD than utility power.

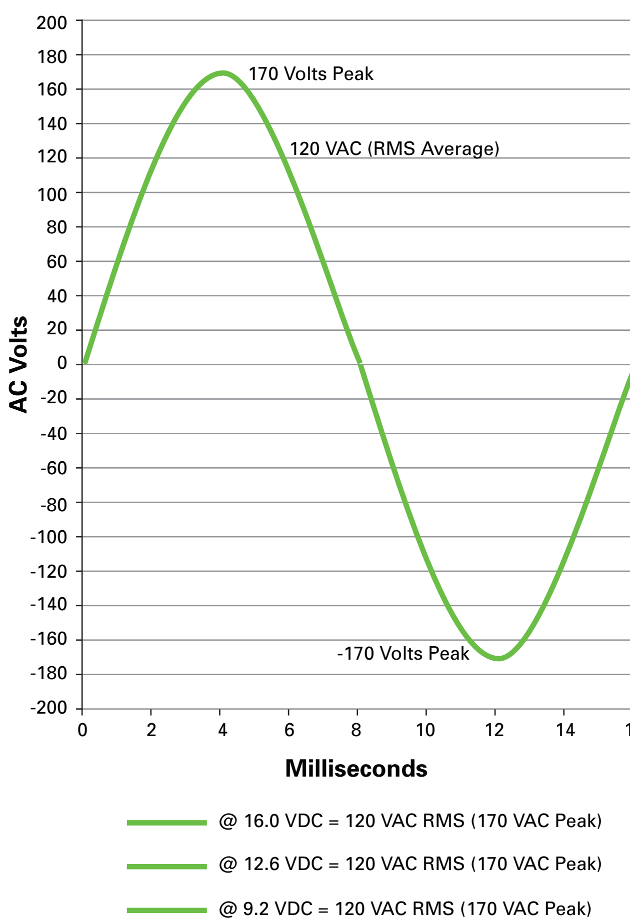
To make this wave form, a true sine wave inverter produces hundreds of positive and negative pulses during each AC cycle. These pulses are then filtered into a smooth sine wave shape. Most true sine wave inverters are able to adjust the duration and timing of each pulse by using very fast digital electronic circuits and/or microprocessor control. This allows the voltage and frequency to be well controlled, ensuring that any AC load within the inverter's power limits will operate properly.

Because the output is a well controlled, very sinusoidal shape, using these inverters for grid-tied applications is possible by the addition of the required safety systems and the additional testing and certification to meet the requirements of UL1741 and utilities.

Stepped Sine Wave Inverter AC Voltage at Low, Normal, and High DC Input Voltages



Pure Sine Wave Inverter AC Voltage at Low, Normal, and High DC Input Voltages



Power rating. Because an off-grid inverter usually has to provide all the power required by the AC loads, its power rating is a critical factor. Fortunately, off-grid inverters include detailed information describing their continuous power as well as short-term "surge" capabilities.

Surge power. The inverter's surge power rating is its ability to provide high power levels for short periods of time (seconds) when certain loads—typically, AC motors, such as well pumps or power tools—are started.

Conversion efficiency. This is how much of the power consumed by the inverter is actually available to power the AC loads. Inverter efficiency can range from 70% to up to 96%. The actual performance depends on the amount of AC loads being powered and the type of wave form provided. Efficiency is typically the worst at very low power levels (less than 100 W) and best at about 25% to 50% of the inverter's continuous power rating.

Idle power consumption. Although the efficiency of an off-grid inverter is very important, be sure to also consider how much power the inverter uses when no loads are being powered—called the idle or tare power consumption. For example, one model may consume 10 W, while another similar inverter might consume 50 W. In just one day, that's a difference of almost 1 kilowatt-hour being consumed (40 W x 24 hours = 960 Wh). Some off-grid inverters use a search mode to reduce energy consumption, turning off all but the search capability when no load is present. Although this is useful in some applications, many homes have AC loads that require power continuously—such as security systems or answering machines—negating any potential energy savings from search mode.

The Xantrex XW series is designed for off-grid as well as grid-intertie systems with battery backup, which is useful in the event of grid failure.

Courtesy www.xantrex.com

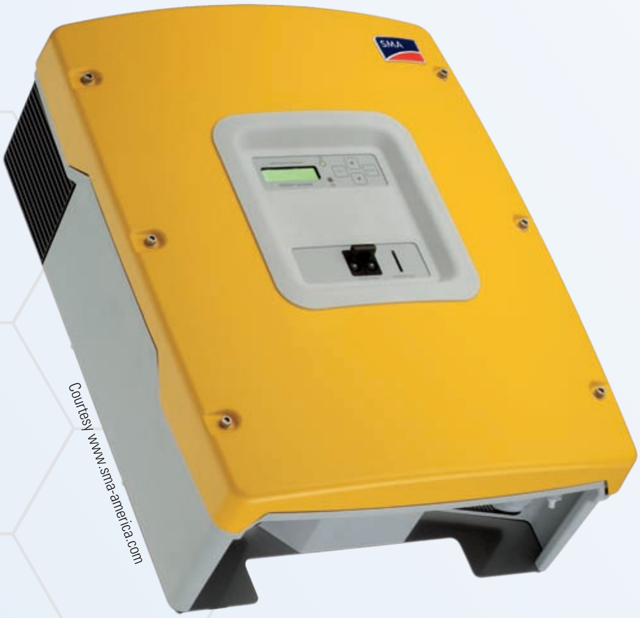
Battery voltage. Most off-grid inverters work with nominal battery voltages from 12 to 48 VDC, with the surge power and conversion efficiency being the best on the 24 and 48 VDC inverters. A few larger inverters (more than 10 kW) are designed to work with even higher voltage batteries—up to 240 VDC—but this requires specialized installation, safety procedures, and even different battery construction. Generally, the benefit of using a battery bank with a higher voltage than 48 VDC is not advantageous compared to the possible hazards it adds, unless the system size is very large (more than 30 kW).

Options. Many off-grid inverters are available with a built-in battery charger and AC transfer switch. This allows connection of a backup source (like the grid or an AC generator) to charge the battery and/or run AC loads when battery power is insufficient. It's a good idea to include this feature even if the application does not have a generator, since this will allow easy future load expansion or periodic battery equalization charging by simply connecting to an AC source, even if only occasionally.

MOBILE. Most mobile inverters are similar to off-grid inverters. Although most are 12 VDC, some 24 VDC systems are used on larger motor coaches and boats, and in military applications. Special mobile inverters are even designed to handle severe vibration conditions or even corrosive environments, such as saltwater spray or alkaline dust. Knowing the requirements of the application is critical to selecting an inverter that will not only operate the loads acceptably, but also work reliably.

While Magnum also makes residential RE system inverters, its ME series is designed specifically for mobile applications.

Courtesy www.magnumenergy.com



Using AC coupling, the SMA Sunny Island inverter can be used in off-grid and battery backup grid-tied systems, as well as to build minigrid village power systems.

GRID-TIED WITH BATTERY BACKUP. A few models are available that can "sell" power back to a utility grid when the battery is full. Having a battery backup system adds considerable complexity to a grid-tied system, but it can be a useful feature for those with frequent or lengthy utility outages or who want to be well prepared for possible natural disasters or emergencies. Be sure that the inverter documentation clearly states that it is designed for grid-tied operation and that it is has been tested and approved to the UL1741 standard for grid-interactivity.

Backup AC load panel. A battery backup system typically requires a separate AC load panel for the circuits that will continue to operate when a utility outage occurs. Installing these panels—and wiring the individual circuits to them—can be time-consuming.

Batteries. Batteries are best placed in a protected location to keep them warmer in the winter and cooler in the summer, and out of reach of children and pets. Be prepared to replace the batteries every three to 12 years depending on their charging regime, usage, capacity, and battery type.

Neutral/ground switching system. The primary difference between a mobile and an off-grid inverter is how the AC transfer switch works. Mobile inverters include additional switching circuits that disconnect the AC input neutral and make a connection between the AC output neutral to the ground conductor when operating in the inverting mode. This prevents a ground fault from occurring when the RV or boat is plugged into a pedestal or shore power. A ground fault can result in shock or electrocution.

Efficiency. In most mobile applications, the engine of the vehicle does most of the battery charging so the inverter's efficiency may not be as critical as with off-grid applications. However, if you spend extended periods of time "boondocking" or parked without running the engine or being connected to the grid, then careful attention to selecting an inverter with the highest conversion efficiency and the lowest idle power consumption is important. The higher performance and longer battery life will be worth the extra money.

AC input capacity. It is important not to pull more AC current through the inverter's AC transfer switch than it is capable of handling. Be sure to follow the manufacturer's instructions and install proper overcurrent protection to prevent damage if an overload occurs.

AC wave form. Although many RVs use modified square wave inverters, many RVs also have sophisticated electronics and sensitive loads, which won't run as well on this type of wave form. Choose a sine wave inverter for compatibility.

Some inverters, like this Aurora PVI series made by Power One, are designed for highly efficient batteryless grid-tied applications.

Efficiency and costs. Backup capability to a grid-tied PV system does come at a cost—the conversion efficiency will be about 5% less than for a batteryless system, and the system cost can be as much as 25% to 50% more due to the additional controllers, batteries, other balance-of-system requirements (combiner boxes; battery cables and enclosures; inverter accessories; critical loads subpanel; etc.) and increased installation time.

BATTERYLESS GRID-TIED. A batteryless grid-tied inverter is designed to do one thing very well—power AC loads from an RE system along with the utility grid and "sell" any surplus energy back to the utility. Because these inverters do not require batteries, the system and installation cost is lower and the efficiency is usually higher. The downside is that the system is unable to provide AC power during a utility power outage even though the sun may be shining or the wind blowing.

Input voltage window range. Most grid-tied inverters are designed to work with a specific PV array configuration or a particular wind turbine. The input voltage of most batteryless grid-tied inverters is very high—many can accept up to 600 VDC and require at least 200 VDC to start operating. However, it is critical that the PV array operate within the inverter's voltage window or damage and/or poor performance may occur.

Tested and certified. To sell power to a utility, a grid-tied inverter has to produce a very accurate sine wave AC output with very low total harmonic distortion (see "AC Output Wave Forms" sidebar) and must be tested and certified to meet safety and performance requirements to protect the utility's infrastructure and personnel. All batteryless grid-tied inverters should be factory-labeled stating that it is designed for grid-tied operation and has been tested and approved to the UL 1741 standard. (For more information on batteryless grid-tied inverters, see "Grid-Tied Inverter Buyer's Guide" in *HP133*.)

Access

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