Pacific Power Source

Application Note

17692 Fitch
Irvine, CA 92614

Phone (USA): 800-854-2433
Phone (Int'l): 949-251-1800
Fax: 949-756-0756
www.pacificpower.com

Selecting an AC power source: Linear or PWM

by Mitchel Orr, Pacific Power Source, Inc.

Understanding the capabilities and differences of linear and pulse-width modulated (PWM) AC power sources is especially helpful to system operators and specifying engineers. Recognizing the capabilities allows them to determine which models meet their requirements. Appreciating the differences allows them to decide which type of AC power source is best suited for the application.

The selection of an AC power source should be based on more than three catalog values of rated voltage, frequency and power. Selection based on incomplete requirements is risky at best. In fact, ignoring real-world requirements may lead to disappointment with product performance or test results or both.

Critical operational capabilities include bandwidth, current and regulation. Other application-specific requirements are size, weight, operating temperature and cost. For many mid-range applications, either linear or PWM switch-mode technology will provide equally satisfactory performance. In other more stringent applications, only one of the two technologies will best meet an operator's particular needs.

Within the United States, commercial mains-supplied AC power is convenient, reliable and usually stable. By intent, mains-supplied AC is inflexible. However, many tests require a wide range of controlled voltages and frequencies. Other tests must support startup surges and the measurement of harmonic currents. Commercial AC power is subject to induced noise and line perturbations. AC power line impedance is uncontrolled in most installations. It is easy to recognize the limitations of commercial AC power. Commercial AC is neither flexible enough nor noise-free enough to allow precision measurements. Unpredictable variations make repeatable controlled tests impossible. Precision AC power source becomes an obvious solution.

A well-instrumented AC power source can deliver precisely managed power to fully characterize a unit under test. The AC power source may be used to present a range of voltages and currents to determine steady-state power needs. In addition, transients, harmonic waveforms and other voltage perturbations may be applied. These features support limit-testing and verification of operational extremes for a unit under test. Using the AC power source's built-in measurement features, loading characteristics of the unit under test can be analyzed.

Load and performance-testing requirements

A rugged power source is essential for use in the production environment. A production source must be convenient to use. It must deliver the prescribed wave shapes, frequencies and power to units under test. For general-purpose testing, ease of reconfiguration is important. Reconfiguration capabilities include: voltage range, frequency range, number of output phases and execution of pre-established voltage limit tests. However, even with very simple of applications, the dynamic power characteristics of the equipment under test must be considered. Many loads are not resistive. As a result, an applied voltage and load current may not be in phase. For the purposes of this presentation, out-of-phase operation is identified as low power factor. (By definition, power factor is the ratio of real to apparent power, but is most often observed as the phase angle difference between voltage and current waveforms.) Additionally, a load may demand peak current many times greater than that predicted by average power consumption. A high peak current condition is identified by crest factor, which is the ratio of peak current to an AC waveform's RMS current. Finally, in many applications, the selected AC power source must provide a reservoir of energy. Reserve energy is necessary to meet startup surge current requirements without distorting the voltage waveform.

Overview of power conversion

Electrical power converters transform electrical energy in one form into electrical energy in another form. An AC power converter can be thought of as a unit with only input and output terminals. From this simplistic perspective, the input-to-output process appears to be simply AC-to-AC power conversion. However, from the implementation perspective, internal power management involves AC-to-DC conversion at the input. The output requires DC-to-AC conversion. Any wide-range AC-to-AC power source includes intermediate processes of AC-to-DC and DC-to-AC conversion. These are not academic considerations. The efficiency of each conversion process has implications for weight, size, temperature rise and cost.

More efficient conversion processes (including amplification) result in smaller, lighter-weight, and cooler-running units. Less efficient conversion processes result in larger, heavier, and hotter-running units. It follows that the efficiency of each type of amplifier is a significant factor in determining size, weight, and temperature rise.

AC-to-AC power conversion results in a reliable source of operator-controlled AC power. The AC mains provide basic power. The converter delivers a tightly controlled synthesized waveform at the prescribed voltage, frequency and power level.

Basic AC-to-AC conversion

Figure 1 illustrates how noisy unregulated AC power is converted to DC. Simultaneously, a controlled low-level precision waveform is generated by an oscillator within the power source. The low-level oscillator's signal is amplified, using the converted DC as an energy source. The result is a stable well-defined high-level AC voltage with prescribed waveshape and frequency.

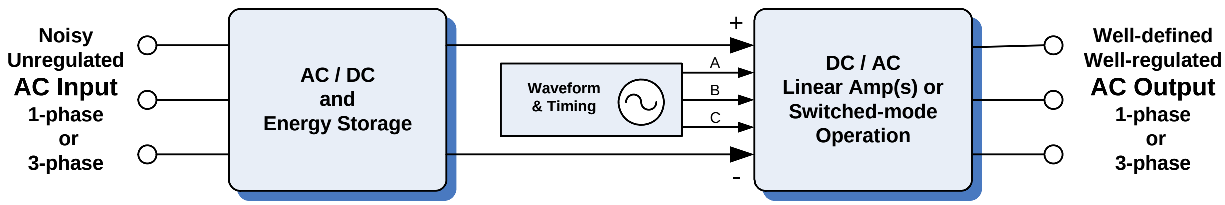

Figure 1. Generic AC-to-AC Power Conversion

The reason for using either linear or switching technology depends on the specific application. For example, consider a non-sinusoidal unity power factor load with a high crest factor. This load requirement is best satisfied by a linear amplifier. High-power linear amplifiers can deliver peak currents (high crest factor) with undistorted voltage waveforms. For another example, consider a load with a very low power factor (large phase angle). Low power-factor requirements are more easily satisfied by PWM switch-mode amplifiers. Switch-mode amplifiers can deliver full current in all four quadrants.

Technological considerations

One must consider the individual testing requirements to determine whether linear amplification or PWM switch-mode operation provides superior performance. In addition, careful evaluation of requirements will determine which of the two technologies provide the more cost-effective solution. Operational requirements include:

- Fast transient response
- High crest factor
- Low output impedance
- Low power factor loads
- Non-linear
- Reactive
- Startup surge current
- Size and weight

Linear AC power source

Linear AC power sources produce low-distortion output waveforms. Linear amplification is achieved by using non-saturating methods. The advantage of linear amplifications is faithful reproduction of the (synthesized) oscillator waveforms. Linear amplifiers have the disadvantage of being very inefficient. Types of linear amplification include class A, B and AB. The letters refer to signal conduction angle. Class A linear amplifiers typically operate at less than 50 percent efficiency. Class B or AB can achieve peak efficiencies greater than 50 percent. As a consequence of low operating efficiency, size and weight can become major issues for linear power sources. However, linear AC power sources feature full-power wide-bandwidth, excellent transient response and the lowest possible output impedance.

Characteristics of Linear-Amplifier Technology

- Very low output distortion
- Wide output bandwidth
- High crest factor handling for wide range of loads without waveform distortion
- Wide range of active output impedance control (optional)
- Higher temperature operation due to class A, B, and AB amplifier inefficiencies
- Larger size due to increased component count
- Higher weight due to increased component count

Basic AC-to-AC linear amplification power conversion

Figure 2 illustrates the operation of an AC-to-AC linear power source. At the input, one-phase or three-phase AC is converted to DC. Following rectification, filtering removes AC-ripple, broadband noise, and intermittent transients. Energy storage overcomes the effects of dropouts and line sags. The stored energy is subsequently used for powering the output amplifier. Simultaneously, a low-level controlled waveform is generated by an oscillator in the power source. As a practical matter, typical waveforms are stored as digital samples. Consequently, synthesized waveshapes are identical, regardless of output frequency. Finally, the waveform is amplified to the required level of voltage and power. When required to manage complex loads, the linear amplifier's output impedance can be fixed or managed through controlled feedback. Finally, the linear amplifier's wide bandwidth is ideally suited to delivering faithfully shaped complex waveforms

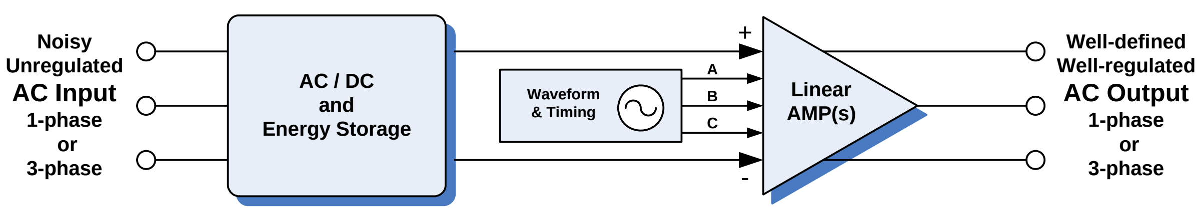

Figure 2. AC to AC Linear Amplification Power Conversion

Switch-mode AC power source

Switch-mode AC power sources use a combination of linear and non-linear methods to achieve waveform amplification. Methods include pulse-width modulation, non-linear amplification and low-pass filtering. Switch-mode amplifiers are highly efficient because they are either fully on or fully off. Consequently, less power is dissipated (lost) in the amplifier than for linear amplifiers with full-range conduction cycles. Switch-mode amplification is called class D. Class D amplifiers provide an output with high harmonic content. An output stage low-pass filter removes high frequency distortion. The output of the low-pass filter is an amplified version of the input signal.

Basic AC-to-AC non-linear (switch-mode) power conversion

Figure 3 illustrates the operation of an AC-to-AC switch-mode power source. Input power processing and oscillator signal generation are identical to those described earlier. However, for switch-mode conversion, the low-level analog signal is not sent directly to a linear amplifier. Rather, it is sent to the input of a pulse-width modulator. The pulse-width modulator operates at a free-running frequency many times greater than the highest frequency in the input waveform.

With zero analog signal amplitude input, the output of the modulator is a rectangular wave with equal positive and negative periods. Consequently, for zero input, the output of the low-pass output filter (figure 3) is exactly zero volts. However, as the width of the modulated pulses follow the polarity and amplitude of the input signal, the filter's output becomes an amplified version of the oscillator input signal. Because the output is derived from pulse-width samples, there is a larger fractional percentage distortion than with a linear class A, B or AB amplifier. However, the output stage efficiency is much greater than for linear amplifiers, typically 80 percent or greater. Lower power loss in the output stage results in cooler operation and smaller size components.

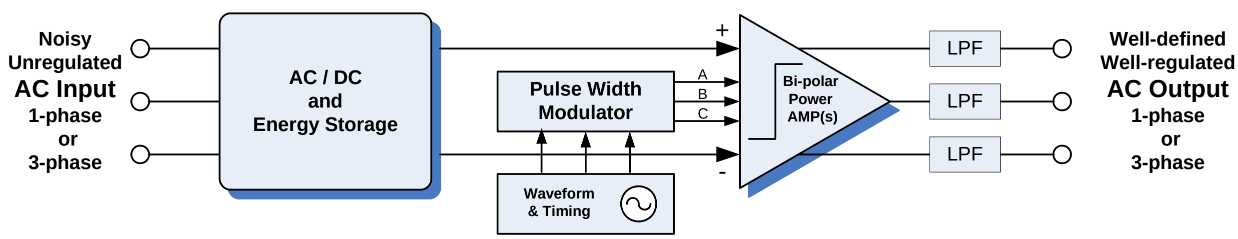

Figure 3. AC-to-AC Switch-Mode Power Conversion

Characteristics of Switch-Mode Technology

- Moderately low output distortion
- Ability to provide full current into very low power factor reactive loads
- Ability to provide full current over full voltage range without derating
- Moderately wide output bandwidth
- Moderate range for (optional) active output impedance control
- Lower weight due to higher amplification efficiencies
- Smaller size due to smaller/fewer components
- Lower temperature operation due to higher amplifier efficiencies
- Limited ability to reproduce complex transient waveforms

Comparison of features and capabilities

Table 1 lists typical applications for AC-to-AC power sources. It is seen that linear technologies provide superior performance for some testing applications. However, PWM switch-mode technology excels for other applications. The conclusion is one must carefully specify the application.

Table 1. Typical AC-to-AC Power Source Applications

Application	Linear	Switch-Mode
DC supply ATE tests	Best	
400Hz, synchronous ATE system	Best	
R&D power line disturbance tests	Best	
Watt-hour meter testing	Best	
Power line disturbance tests	Best	
Production life tests (frequency conversion)		Best
Circuit breaker tests		Best
Safety compliance tests		Best
Commercial appliance test and burn-in		Best
Motor performance and safety tests		Best
Note: In a particular situation, either amplifier type may be more appropriate.		

Table 2 lists generic benefits of each of the two technologies. It is seen that no single technology excels in all areas. The conclusion is one must carefully specify these requirements. However, over-specifying may lead to avoidable cost, weight and environmental concerns.

Table 2. Extreme Pros and Cons of Each Technology

Feature / Capability	Linear	Switch-Mode
Highest amplifier efficiency		Best
Lowest operating temperature		Best
Lowest weight		Best
Smallest size		Best
Lowest cost		Best
Low-power factor handling		Best
Lowest harmonic distortion	Best	
Highest small-signal bandwidth	Best	
Highest large-signal bandwidth	Best	
Active impedance control	Best	
Highest crest-factor	Best	
Highest startup surge current	Best	

Under conditions of mid-range performance, switch-mode sources are more cost-effective. For the absolute highest mid-range performance, linear amplifiers are more capable. However, there is no single-parameter right-or-wrong solution when it comes to selecting a linear or a switch-mode AC power source. The appropriate solution depends entirely on the full set of requirements, including:

- Output voltage range
- Output current requirements, including inrush and overload
- High peak current for non-linear (high crest factor) loads
- Phase angle of output current (power factor)
- Accurate replication of custom or high harmonic waveforms or both
- Fast transient capability
- Amplifier output voltage distortion
- Amplifier output impedance and control
- Size, weight, and efficiency limits
- Environmental needs and limits
- Performance versus price considerations

In conclusion, given a set of realistic requirements, one can make an objective decision about which technology provides the appropriate solution. When the exact requirements are not obvious, knowledgeable vendor application support is often the best path to success.

Mitchel Orr is sales manager for Irvine, Calif.-based Pacific Power Source (PPS), which designs and manufactures a wide range of high-performance AC power sources. PPS produces both linear and switch-mode products. The PPS AMX series models are based on linear technologies. The PPS ASX series models are based on PWM switch-mode technologies.