

# Production power on a budget: How to generate clean reliable power, Part 2

BY GUY HOLT

THIS IS THE SECOND IN A THREE PART SERIES on the use of portable generators in motion picture production. We pick up after establishing in Part 1 that when non-linear lighting loads draw current from a high impedance power source, like a portable generator, harmonic-induced voltage drop results in voltage so distorted that it can no longer serve as a reliable power source. In this second part, we establish the generator itself as a contributing source of harmonic currents in a distribution system and look at other loads that draw harmonics.

Portable generators are a source of harmonics because of the way their alternators are designed. An alternator generates electricity by rotating electromagnets in close proximity to copper coils. The electromagnets are mounted on a shaft, called the rotor, and rotated within a cylindrical housing called the stator. The stator assembly consists of insulated windings (stator coils) positioned around the rotor. When the rotor is rotated, the moving electromagnets induce an electrical current in the armature coils. Each time the rotor makes one complete revolution, one complete cycle of AC is generated. Since the rotor rotation swaps the positions of the north and south poles of the magnetic field at different points in time, the voltage generated alternates between + and - in a sinusoidal fashion, and each full engine rotation produces one complete AC sine wave. To maintain a constant AC frequency (Hz), the rotor must rotate at a constant speed. Voltage is a function of the strength of the magnetic field of the rotor's electromagnets created by the excitation current and the electromagnets' distance from the armature coils. The number and the way the stator coils are connected determine the phase of the power generated. The stator coils are connected to the electrical outlets. Given the mechanics of generators, the shape of the rotor and the source of the excitation current can have a direct effect on the shape of the resulting voltage waveform.

For instance, a square pole head will generate a square flux wave. Since a square flux wave will generate many odd harmonics in the stator windings, generator manufacturers shape their pole heads to generate as sinusoidal a voltage waveform as possible in order to reduce the generation of voltage waveform distortion. To make the

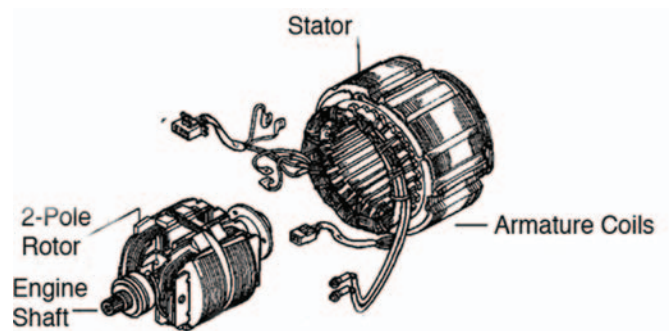


Figure 1 – The slightly beveled pole tips of a Honda EX5500 rotor

flux wave more sinusoidal, the pole tips are beveled. This increases the air-gap at the pole tips, increasing the resistance of the flux path. How carefully a manufacturer physically shapes the pole heads of the generator's rotor contributes to its "waveform deviation factor." Waveform deviation factor is an indication of the degree that a generated voltage differs from a perfect sine wave. It is typically expressed as a measurement of the total harmonic distortion (THD) of the inherent voltage waveform when the generator is unloaded.

Despite their best efforts, generator manufacturers aren't able to produce a perfectly uniform magnetic field in a working AC generator (not even power plant generators), so some degree of voltage waveform distortion exists, and the voltage-time relationship deviates from a pure sine function. Typically, the distortion of grid power is very small (less than 2% THD), but nonetheless it exists. It is an altogether different situation when it comes to portable generators. Since there is a direct trade-off between generator cost and quality of the power waveform, voltage distortion in the original power waveform varies greatly between types of generators. While these distortions are generally small relative to the distortion that can be caused by non-linear loads, they may still be significant because the harmonics that both sources generate will sum in a distribution system.

Depending on their design, small portable generators can range from less than 1% THD to 30% THD. At the upper part of this

range there is the very real potential for the harmonics of the power generated contributing to voltage waveform distortion in the distribution system that can result in overheating and failing equipment, efficiency losses, circuit breaker trips, excessive current on the neutral wire, and instability of the generator's voltage and frequency. For this reason, it is well worth our while to look at the various types of portable generators available and how they interact with the harmonic currents drawn by a typical non-linear lighting load—a 1.2 kW HMI lamp with non-power factor corrected electronic ballast.

The two predominant types of generators available at tool rental companies are brushless and AVR generators. Since they are the least suited for motion picture production applications, let's look at brushless generators first.

## Brushless generators

To generate the excitation current that magnetizes the rotor's electromagnets, brushless systems use two sets of rotors on one shaft. The larger one produces power as described above. The smaller one is an exciter. Using a rotating armature with a rectifier, it produces a fixed DC voltage, which is used to excite the main rotor

electromagnets. Such a configuration is the most reliable from a mechanical standpoint because brushes and slip rings are not used. Unfortunately for us, brushless gen-sets provide poor power quality (see **Figure 2**).

With THD as high as 30%, brushless generators do not interact well with non-power factor corrected HMI lamp and fluorescent ballasts. As is evident in **Figure 3**, when the harmonics drawn by a 1.2 kW ballast encounter the relatively high reactive impedance of a brushless system, voltage harmonics are generated that when added to the harmonics of the original generated power waveform results in appreciably flat-topped voltage.

With fixed excitation, the voltage output of a brushless generator will also drop under load due to its internal impedance. The output voltage will also depend on the power factor of the load. To maintain output voltage under varying loads, more expensive generators use an Automatic Voltage Regulator (AVR.)

## AVR generators (analog)

Generator AVRs vary widely in design, but on the most fundamental level, an AVR regulates voltage output by first sensing the voltage level generated in separate excitation windings in the stator and then

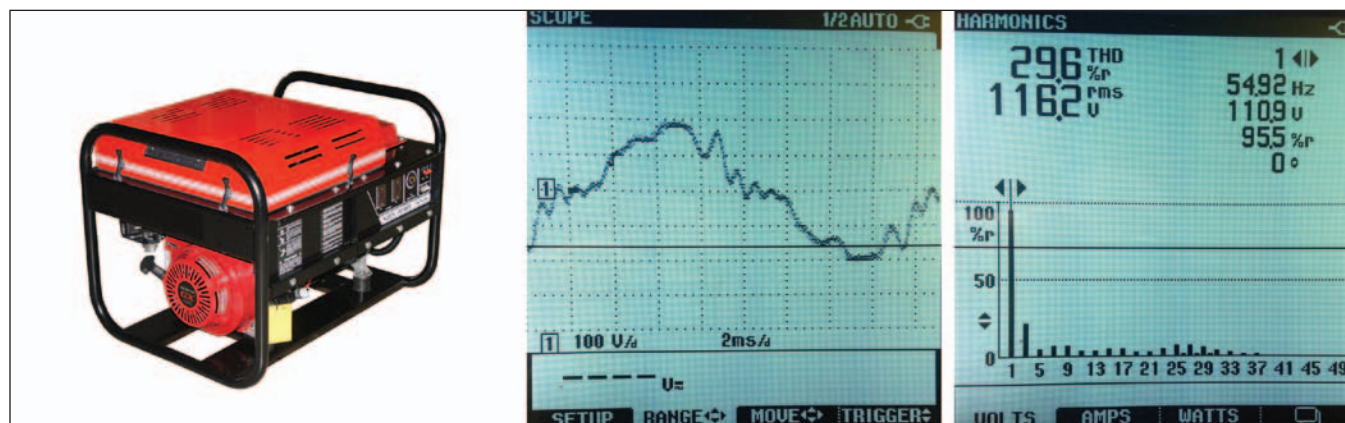


Figure 2 – The inherent voltage waveform of a brushless generator (left) exhibits close to 30% THD (right).

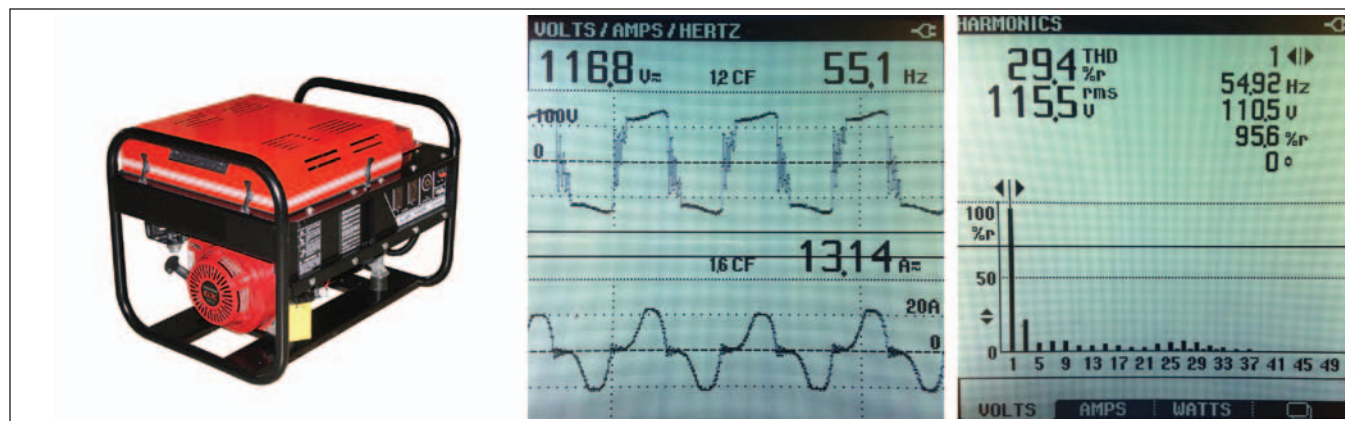


Figure 3 – Harmonic induced flat topping of the voltage of a brushless generator caused by a 1.2 kW HMI lamp ballast (left). The FFT of the distorted voltage generated when the harmonic currents drawn by a 1.2 kW ballast encounter the high impedance of a brushless generator (right).

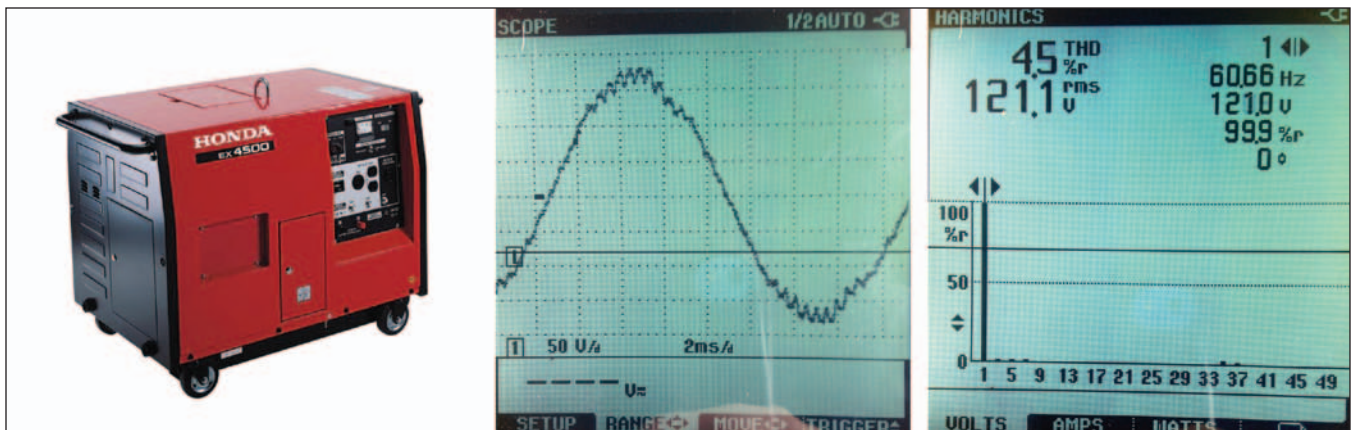


Figure 4 – The inherent voltage waveform of an AVR generator (left) exhibits a THD of 4.5% (right).

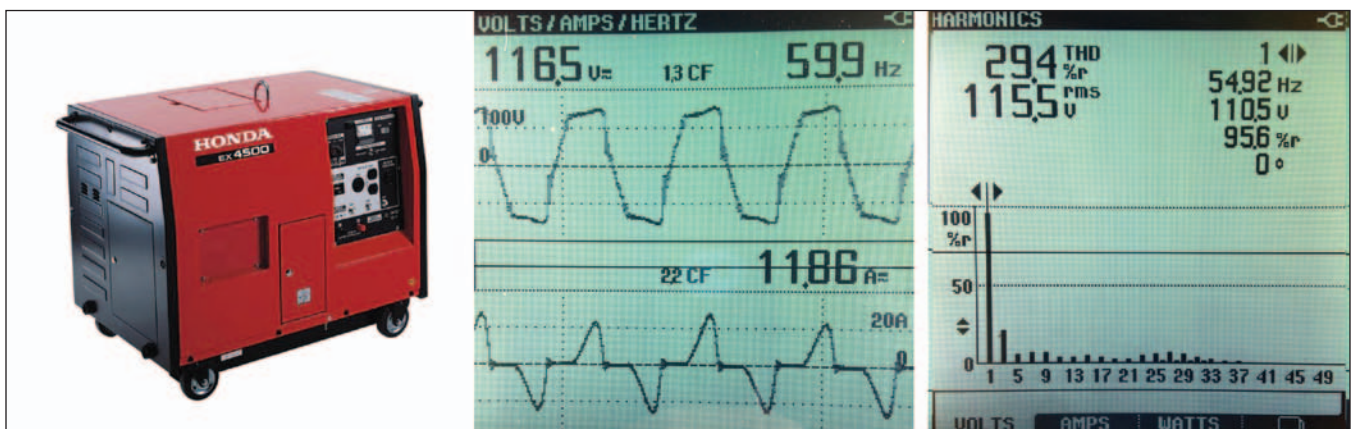


Figure 5 – Harmonic induced flat topping of the voltage of an AVR generator caused by a 1.2 kW HMI lamp ballast (left). The FFT of the distorted voltage generated when the harmonic currents drawn by a 1.2 kW ballast encounter the high impedance of an AVR generator (right).

compares it to an internal reference (typically a zener diode.) If the voltage is too low, a transistor passes excitation current to increase the field strength in the rotor's electromagnets. If the voltage is too high, the transistor cuts the excitation current to decrease the rotor field strength. It is this ON and OFF action of the transistor that gives the voltage output of AVR generators its characteristic step shape that more closely resembles a true sinusoid (with a THD of 4.5%) than that of a brushless system (see **Figure 4**).

Even though automatic voltage regulation reduces reactive impedance and waveform deviation to less than 5% THD, when added to the voltage harmonics induced by the distorted current drawn by a 1.2 kW HMI lamp ballast, the resulting THD (evident in the oscilloscope shots in **Figure 5**) is still sufficient to cause excessive heat and equipment failure.

## PWM inverter generators

It is an altogether different case with the pulse width modulated (PWM) inverter generators found almost exclusively at film rental houses. As is evident in the oscilloscope shots in **Figure 6**, the less

than 1% THD and low impedance of inverter generators results in near sinusoidal voltage (with a THD of 4.2%) even when supplying the distorted current drawn by a 1.2 kW non-power factor corrected ballast (more on this in Part 3 of this series).

## Test results

With the exception of the inverter generator, these oscilloscope shots demonstrate that plugging a HMI lamp ballast into a small portable generator can result in severe voltage waveform distortion. Given the high impedance of brushless and AVR generators, and the potentially high THD value of their inherent power waveform, you have a situation where even a small amount of harmonics being drawn by a load will result in a large amount of harmonic distortion of the voltage. The oscilloscope shots demonstrate clearly these small portable generators present a perfect electrical storm where the drawing of any harmonic currents results in a very high degree of voltage distortion.

To make matters worse, given the increasing prevalence of non-linear light sources in production today, it is likely that the



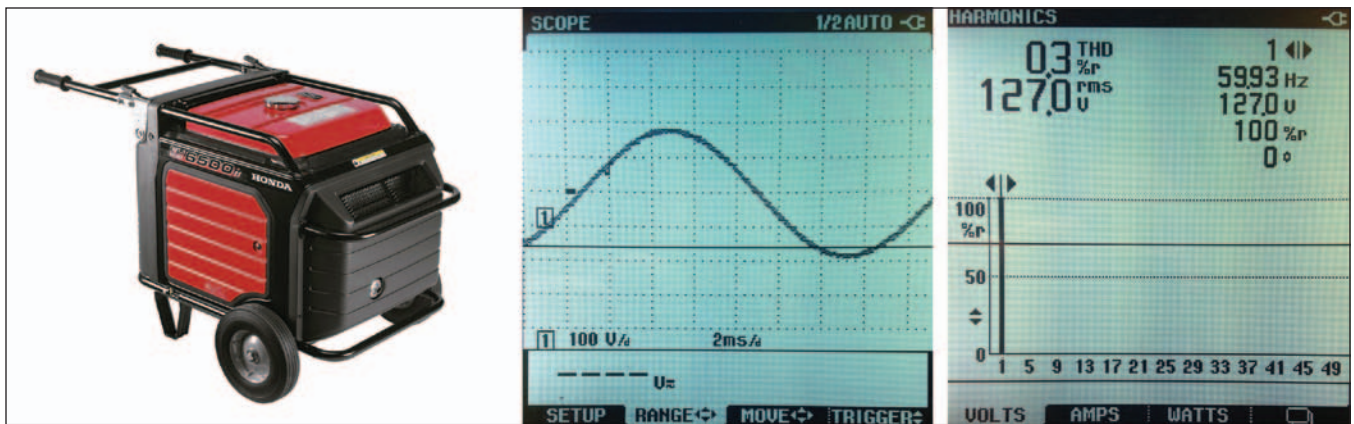


Figure 6 – The inherent voltage waveform of an inverter generator (left) exhibits a THD of less than 1% (right).

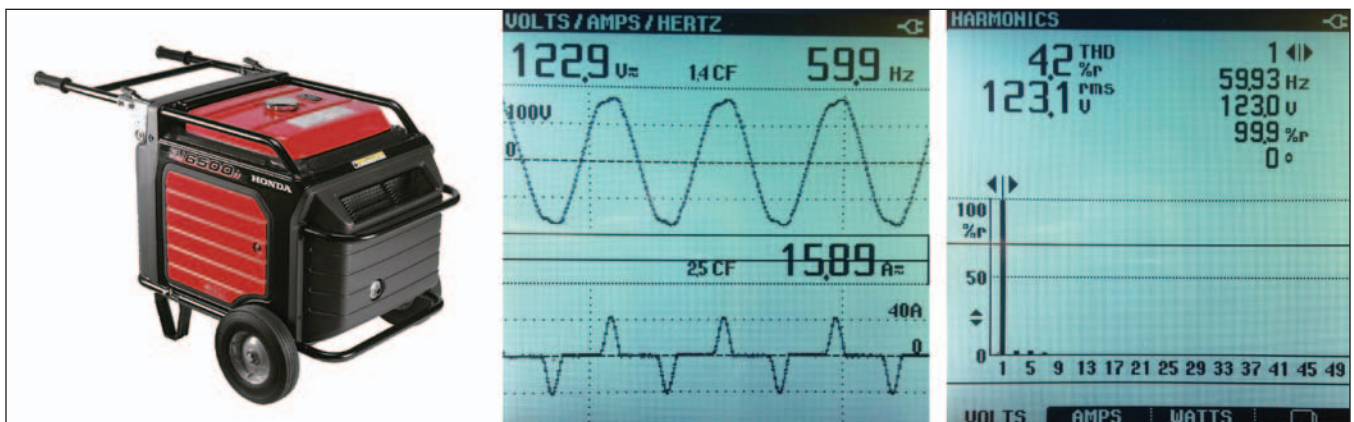


Figure 7 – Because of their low impedance and near sinusoidal voltage, inverter generators exhibit very little voltage waveform distortion (top left) as a consequence of the harmonics drawn by a 1.2 kW ballast. The FFT of the nearly pure sine wave provided by inverter generators despite the harmonic currents drawn by a 1.2 kW ballast (right).

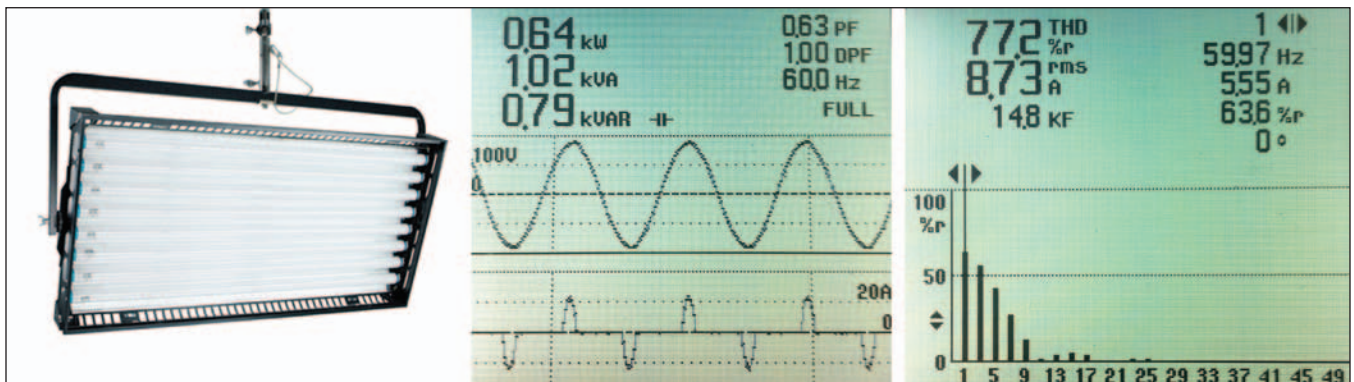


Figure 8 – The spiked current drawn by a Kino Image 85 with non-PFC conventional ballast (lower left). The FFT of the harmonics making up the distorted current waveform drawn by a Kino Image 85 fixture (right).

percentage of the generator's capacity taken up by non-linear loads will be very high. When you look around a set these days, linear loads (quartz lights) are greatly outnumbered by non-linear loads such as HMIs, fluorescents, and LEDs. Without a doubt it is a whole new world and one in which it is critically important to understand the sources of harmonics and have a working knowledge of the problems they can cause.

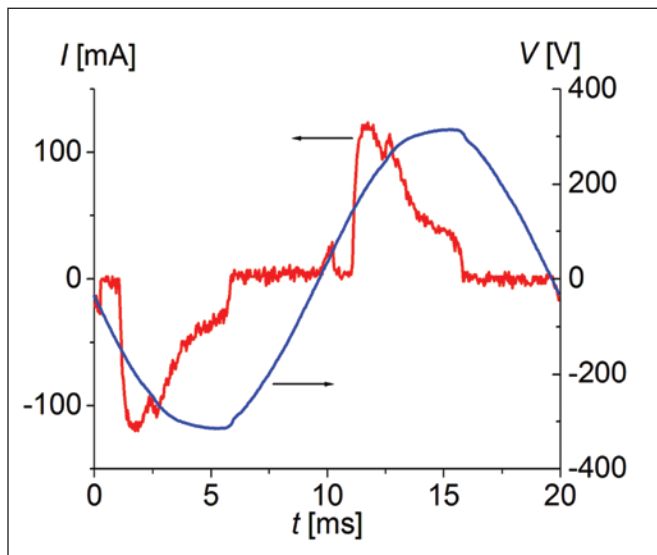
## Understanding the sources of harmonics

In Part 1 of this series, we explored in depth why the diode-capacitor front end of non-power factor corrected HMI ballasts draw a distorted current that is rich in harmonics. Electronic fluorescent

ballasts likewise incorporate diodes and capacitors to first convert the AC input to DC before converting it back to AC. How they differ from HMI lamp ballasts is in the frequency and shape of the final AC waveform. In the case of an electronic fluorescent ballast, the ballast's switch-mode converter generates a high frequency (>20 kHz) arc that excites the phosphors in the fluorescent tube to generate light. In the case of an electronic HMI lamp ballast, the switch-mode converter generates a low frequency (75 or 300 Hz) square wave that creates an arc between electrodes. But, since both utilize capacitors to smooth rectified AC to DC, they each draw current in bursts and generate harmonics (see **Figure 8**).

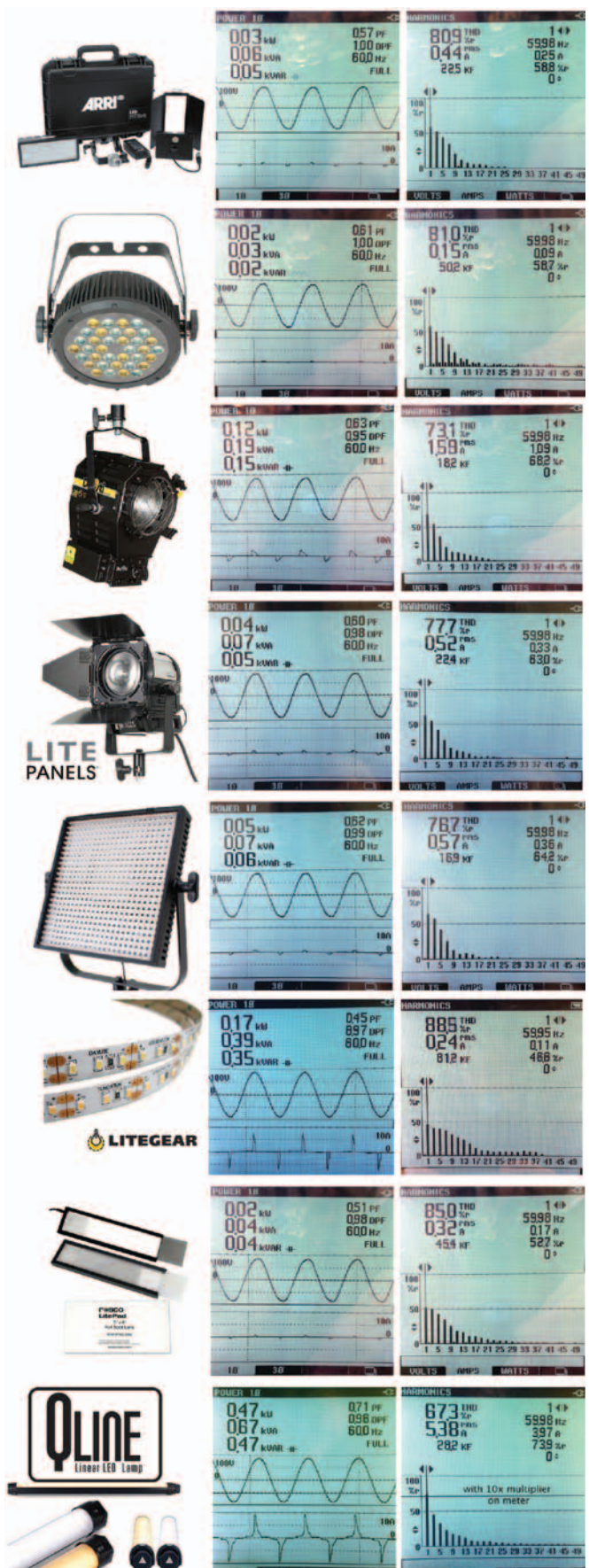
LED luminaires are likely to generate harmonics because direct current (DC) must be applied to the LED diodes to keep them from flickering. To operate them on AC mains power therefore requires some type of AC-to-DC converter. Switch-mode power supplies are almost universally used for this purpose.

As **Figure 9** illustrates, the switch-mode power supplies used in LED AC power supplies can draw a very distorted current, and can result in current that is significantly phase-shifted with respect to the sinusoidal voltage waveform. For instance, the AC power supply that Litepanels uses for their 1x1 panel arrays have a leading power factor of 0.62 and generate high harmonic distortion (THD upwards of 68.1%). At these levels, the AC power supplies used with LEDs can have an adverse effect on power quality similar to that of HMI and fluorescent lights.



**Figure 9** – The very distorted current drawn by an LED AC power supply (red trace) is significantly phase-shifted with respect to the sinusoidal voltage waveform (blue trace).

**Figure 10 (Right)** – In order from top to bottom above LED lights that draw harmonic currents include the ARRI Locaster, the Chauvet Professional Amber/White SlimPAR Pro, the Super Series of De Sisti Studio Fresnels (the F6T and F10T), the Litepanel Sola 4 Fresnel and 1x1 Panel, the LiteGear Lite Ribbons, the Rosco LitePad, and Quasar Science Q-Line LED tubes.





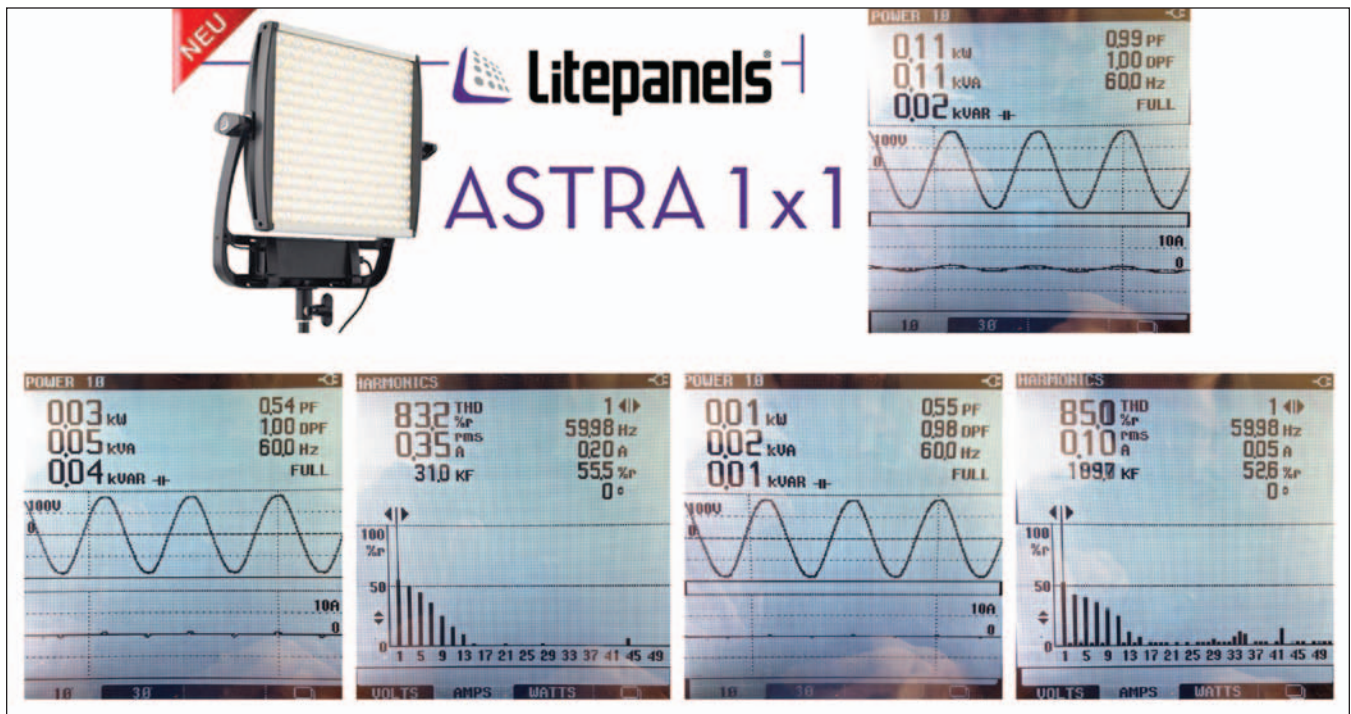


Figure 11 – Bottom left the harmonics drawn by a 1x1 Litepanel Astra dimmed 50%. Bottom right dimmed to 25%.



Figure 12 – Since this package of non-PFC 2.5 kW HMI key light and array of 24 Quasar LED tubes for daylight fill will draw 48 A, one would think it could operate on a 6,500 W generator, but the harmonics drawn by these loads will cause severe voltage waveform distortion.

Litepanels are not the only LED fixtures that draw distorted current. Half the luminaires I tested in the inventories of Boston rental and lighting sales companies have power factors that range from 0.45 to 0.63. These fixtures also generated harmonic distortion that ranged from 75-85% THD.

Some of the LED luminaires that did not draw a distorted current at 100% output did when dimmed. For instance, the power factor of the new Litepanel Astra 1x1 dropped from 0.99 to 0.54 when dimmed 50% (THD increased to 83.2%). (See FFTs for the Litepanel Astra in **Figure 11** at 50% and 25%).

One could argue that the wattage of LED fixtures is so low that the harmonics they draw don't matter from a practical standpoint. While that is true to a degree, when used as the predominant source of light, the harmonics drawn by even small LED fixtures like the Quasar Science LED tubes used for daylight fill in **Figure 12** will accumulate and effect power adversely when used in quantity.

Since it appears that harmonics are here to stay, we must adjust our thinking on electrical distribution system design. Not only must we anticipate non-apparent loads and the adverse effects of voltage waveform distortion, we must also take precautions—especially given the amount of digital processing on set these days. Since the majority of digital processing-based equipment derives its internal DC power from AC power switched by a switch-mode power supply, harmonic problems will first become evident in this class of equipment for the reasons discussed in Part 1 of this series.

## Conclusion

To summarize what we have discovered in these first two parts, the magnitude of voltage waveform distortion in a distribution system depends upon the quality of the original applied power waveform as well as the relative size of the nonlinear loads with respect to the source impedance and capacity of the power generating system. That is, the amount of voltage distortion increases as distortion of the generated waveform increases and there is an increase in the percentage of nonlinear loads taking up the total capacity of the power generating system. For this reason, when designing a distribution system, it is important to consider the specific magnitude and order of the harmonics drawn by each type of lighting load that it will power.

Taking into account the interaction between these elements will enable us, in the next and last part of this series, to design lighting packages that result in cleaner and more stable power, enabling the operation of more lights on small portable generators than has ever been possible before. ■



**Guy Holt** has served as a gaffer, set electrician, and generator operator on numerous features and television productions. He is recognized for his writing on the use of portable generators in motion picture production (available soon in book form from the APT Press). Guy has developed curriculums on power quality and electrical hazard protection that he has taught through the IATSE Local 481 Electrical Department's "TECs" Program. He is the owner of ScreenLight & Grip, a motion picture lighting rental and sales company that specializes in innovative approaches to set power using Honda portable generators.