# Production power on a budget: How to generate clean reliable power, Part 3

BY GUY HOLT

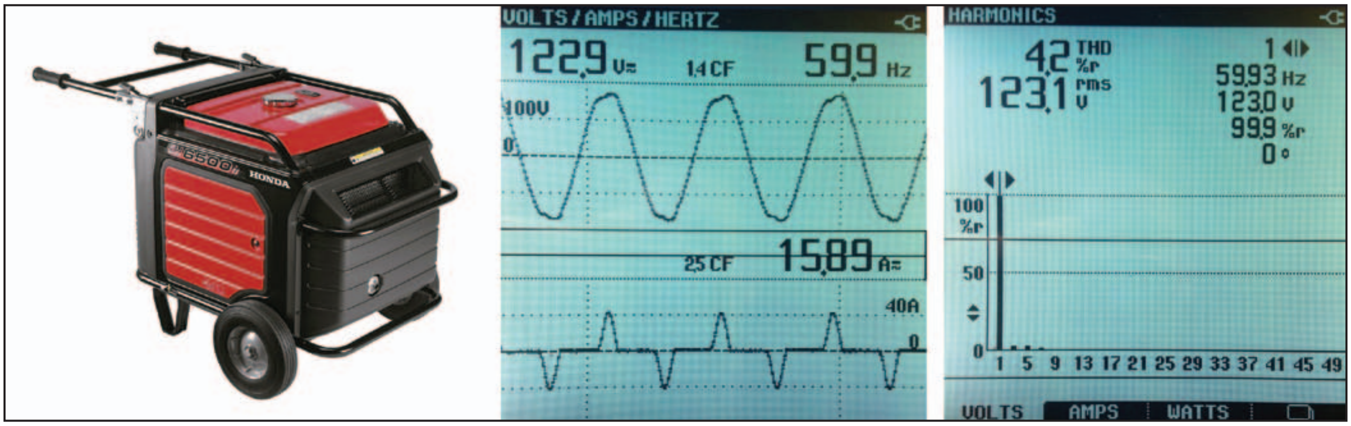


**Figure 1 - Inverter generators exhibit significantly less voltage waveform distortion than other types of generators when powering the same 1200 W non-linear load.**

IN PART 1 OF THIS SERIES, we discovered that when non-linear lighting loads (HMIs, Kino Flos, and LEDs) draw current from a high-impedance power source like a portable generator, harmonic-induced voltage drop at only the peak of the voltage waveform results in voltage so distorted that it can no longer serve as a reliable power source. In Part 2, we discovered that the magnitude of this voltage waveform distortion depends upon the quality of the original power waveform, its source impedance, and the harmonics drawn by the load. Overcoming these impediments to generating clean stable power will enable us in this part to build a production system capable of operating more lights on small portable generators than has ever been possible.

In Part 2, we discovered the first building block of such a system: the pulse-width modulated (PWM) inverter generators we tested. In our load tests, we found that a Honda EU6500is inverter generator exhibited significantly less voltage waveform distortion than other types of generators when powering the same non-linear load (See **Figure 1**.) Even though the same harmonic currents were drawn by the load, the power output of the EU6500is retained an overall sinusoidal shape because of its purer original power waveform and lower impedance. Because of the appreciable reduction in voltage flat-topping, lights such as HMIs, Kino Flos, and LEDs, that are dependent on peak voltage to operate, will operate more reliably on inverter generators. What is it about inverter generators that make this possible?

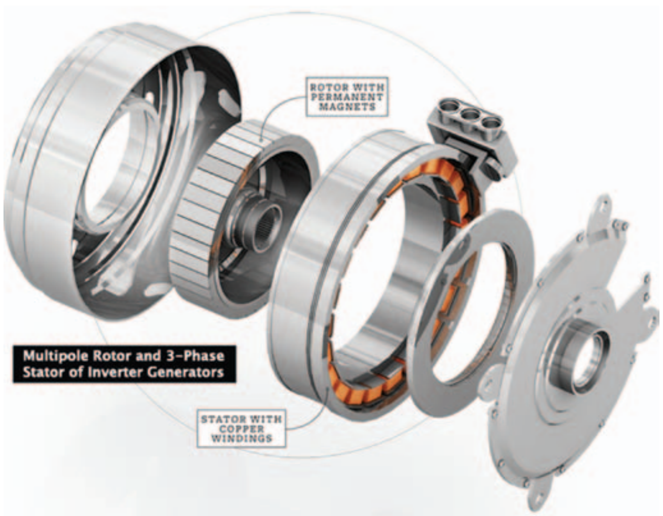


**Figure 2 – In an inverter generator up to 36 rotor magnets rotate in multiple three-phase stator coils to generate up to 300 AC sine waves, creating more power in a single rotation of its engine.**

As can be seen in **Figures 2**, **Figure 3**, and **Figure 4**, they take a radically different approach to generating AC power than do conventional AVR (automatic voltage regulator) generators. Unlike the simple two-pole alternators found in AVR generators, an inverter generator uses a core that consists of multiple stator coils and multiple rotor magnets (See **Figure 2**).

Each full rotation of the engine produces more than 300 cycles of three-phase AC at frequencies up to 20 kHz, which is considerably more electrical energy per engine revolution than is produced in conventional two-pole AVR generators. The power generated by the multi-pole core goes into an inverter module where it is first converted to high voltage DC before being switched to low voltage AC by microprocessor controlled insulated gate bi-polar transistors (IGBTs.) Let's look at this process in more detail using the schematic of an inverter generator in **Figure 3**.

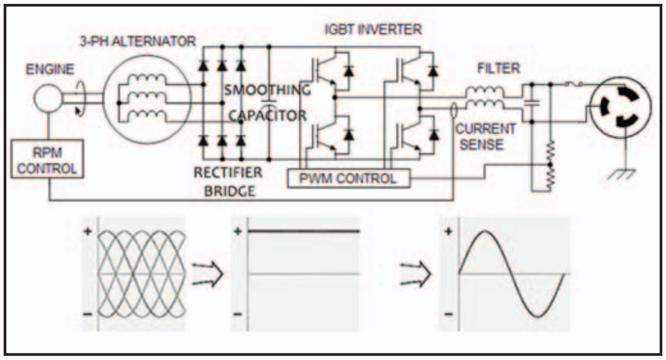


**Figure 3 – Power stages of an inverter generator.**

The power converter front end consists of a fixed diode bridge rectifier that converts the three-phase AC power to pulsed DC (about 200 V in at least one unit we've tested). By charging as the voltage ascends and discharging as it descends, smoothing capacitors fill in between the voltage peaks to create a high voltage DC power. AC is generated from the DC by a microprocessor pulse width modulating it by switching the IGBTs according to the control logic illustrated in **Figure 3**. Because IGBTs can turn on in less than 400 nanoseconds and off in approximately 500 nanoseconds, they are ideal for the high switching speed necessary to create a true sine wave in this fashion.

There's more to inverter generators than just the clean voltage waveform that makes them the best choice for motion picture applications. As we have seen, inverter generators take a radically different approach to generating power than do conventional generators. That difference extends also to how voltage is regulated. As discussed in Part 2 of this series, conventional generators use an automatic voltage regulator (AVR) to maintain a sinusoidal voltage output within tight limits. It does so by first sensing the voltage level generated in a separate sensing coil in the stator and then comparing it to a reference. (The reference is often a Zener diode, which is a very stable voltage device.) The desired voltage level is set by adjusting a rheostat. The AVR compares the set value to the sensor voltage and generates an excitation current to increase or decrease the field strength in electromagnets in the rotor.

The amount of excitation current required to maintain the generator output voltage constant is dependent on the load on the generator. If the output voltage from the stator coil dips due to a drop in engine speed from an increase in demand, more current is fed by the AVR to the rotating electromagnets through the excitation circuit. This increases the magnetic field around the electromagnetic poles of the rotor, which induces a greater voltage in the stator coils and the output voltage is brought back up. While AVR systems

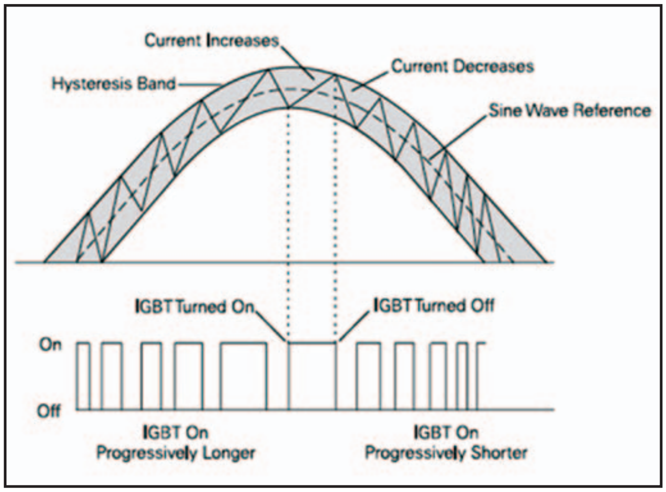


**Figure 4 – By rapidly switching IGBTs (bottom) the inverter microprocessor converts DC to pulse width modulated AC (top.)**

provide a nice sinusoid, they are not ideal because they are slow to respond to transient loads that bog down the engine. This slow response causes voltage to oscillate since it can take several AC cycles for the AVR system to hone in on the set value. This voltage oscillation increases the reactive impedance of the generator and contributes to the voltage flat-topping under non-linear loads that we saw in Parts 1 and 2 of this series.

By way of comparison, inverter generators greatly reduce reactive impedance by breaking this mechanical link between voltage output and the generator's engine. Since the inverter completely processes the raw power generated by the alternator (converting it to DC before converting it back to AC), the AC power it generates is completely independent of engine speed. In fact, the microprocessor controller can vary the engine speed without affecting the voltage or frequency of the power the inverter module outputs. Now that the inverter module separates the internal reactance of the engine from the power output, non-linear loads encounter very little impedance and, as is evident in these oscilloscope shots of a non-power factor corrected HMI operating on a traditional AVR generator and an inverter generator there is considerably less voltage distortion at the load bus of the inverter generator. The net benefit to filmmakers,

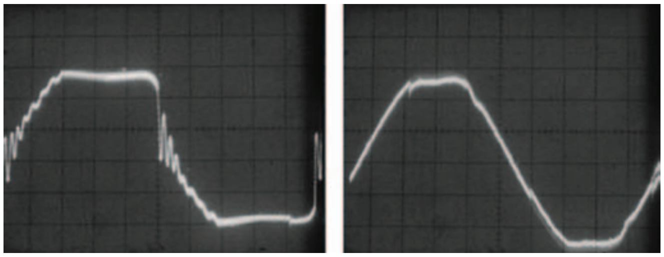

**Figure 5 – (Left) Conventional AVR generator with 1200 W non-PFC electronic ballast. (Right) Inverter generator with 1200 W non-PFC electronic ballast.**

as can be seen in **Figure 5**, is that non-linear loads, e.g., HMI, Kino, and LED ballasts, do not adversely affect the power of inverter generators as they do the power of conventional AVR generators.

As we saw in Part 2, the other impediment to generating clean stable set power is the harmonics drawn by non-linear lighting loads, such as HMIs, Kinos, and LEDs. Elimination of these harmonics will enable us to operate more lights on small portable generators than has ever been possible before because, not only do power factor-corrected lights not induce voltage waveform distortion, but they also draw less current, which means that you can put more of them on inverter generators like the Honda EU7000is.

To eliminate harmonics we must first understand how they are created by the smoothing capacitors used in ballasts to convert the rectified AC (pulsed DC) to continuous DC. As illustrated in **Figure 6** (top), the smoothing capacitors draw current from the point where the ascending input voltage is greater than the voltage stored in the capacitor to the point where the voltage peaks**.** Since the capacitors have only this short interval as voltage ascends to receive their full charge, they draw current in bursts of high amplitude that are phase shifted relative to the voltage (illustrated in **Figure 6** bottom). Rich in harmonics, this pulsed current now leads voltage. It is the voltage drop that occurs when these high amplitude bursts of current encounter the impedance of a soft power source, such as an AVR generator, that distorts the voltage waveform and causes the voltage flat topping we see in **Figure 5**.

To draw a sinusoidal current without harmonics requires that the ballast's smoothing capacitors draw current throughout the AC cycle rather than just a brief portion of it. A power factor correction (PFC) circuit accomplishes this by boosting the rectified supply when it is lower than the voltage on the smoothing capacitor so that the capacitor charges throughout the AC cycle.

The net result is that current flowing into the smoothing capacitors approximates a sine wave rather than abrupt pulses. The PFC chip must track the input waveform in real time, making adjustments for both the input voltage and load current. The net result is that the current drawn by the ballast approximates a sine wave rather than abrupt pulses.

As can be seen in the current and voltage waveforms of fluorescent ballasts without power factor correction and with power factor correction in **Figure 7**, PFC circuits can substantially increase power factor (to as much as .98), making PFC ballasts very nearly linear loads. As a result, the ballast uses the supply more efficiently, generates minimal line noise, and generates less heat, thereby increasing their reliability. Unfortunately PFC circuitry is not cheap (it accounts for 25% of the cost of a 1.2 kW ballast), and since it is not mandated in the US as it is in the EU for power supplies over 75 W, you typically don't see it in ballasts under 6 kW in this country. (It is essential to the reliable operation of big HMIs.)

From the results of these tests the outline of a better production system is beginning to take shape. If there is one conclusion to be drawn, it is that, when your lighting package consists predominantly of non-linear light sources, it is essential to have PFC circuitry in the power supplies and to operate them on an inverter generator. This

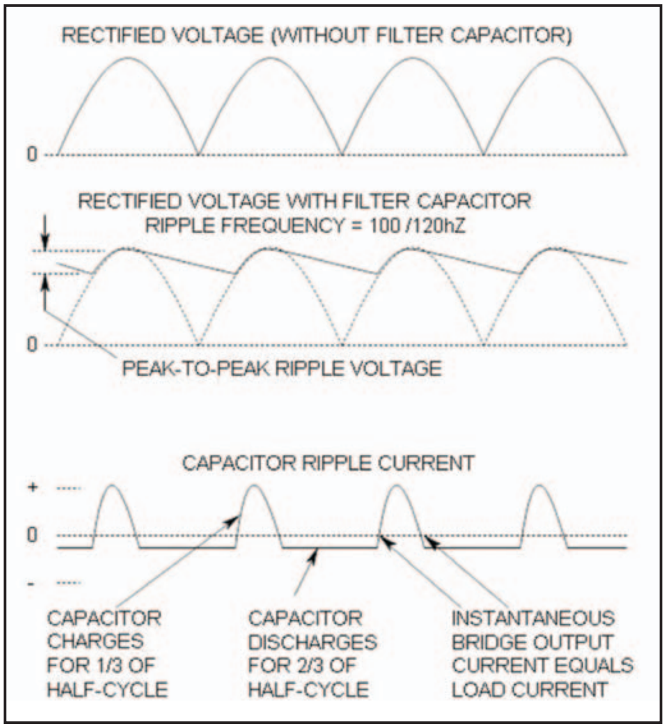


**Figure 6 – Smoothing capacitors**

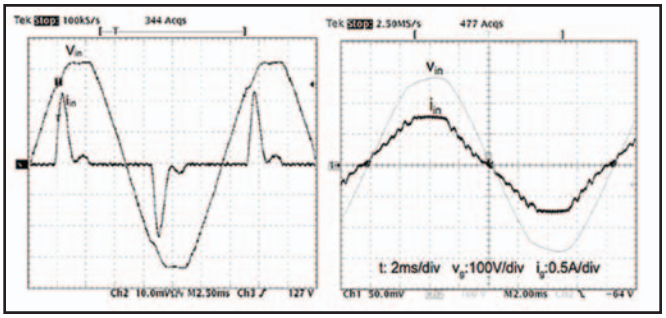


**Figure 7 – Current and voltage waveforms of fluorescent ballasts without power factor correction (left) and with power factor correction (right.)**

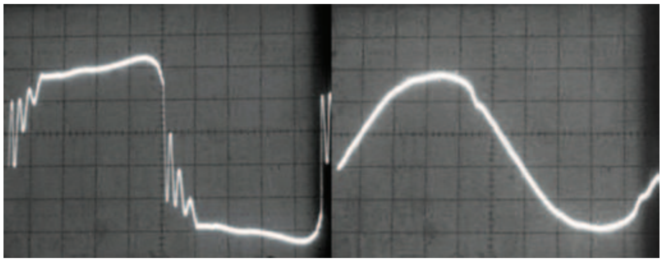

**Figure 8 – (Left) Power waveform distorted by non-PFC 1200 W HMI ballasts on conventional generator. (Right) Near perfect power waveform of the same lights with PFC ballasts on inverter generator.**

combination of a nearly linear load operating on the near sinusoidal waveform of a low impedance inverter generator results in undistorted voltage capable of powering larger lights, or more small lights, than has ever been possible before on portable generators.

For example, the severely distorted waveform on the left of **Figure 8** is the result of a lighting package consisting of non-PFC HMIs and Kino Flos operating on an AVR generator. The power waveform on the right is the same package of lights but with PFC ballasts operating on an inverter generator. The difference between the resulting waveforms is startling. Even though we are running the same overall load, the fact that the ballasts are power factor corrected and operating on a low impedance power system, results in virtually no power waveform distortion. Lights like HMIs, Kino Flos, and LEDs, that draw power only at the peak of the voltage waveform, will operate more reliably and with greater efficiency on the cleaner waveform of an inverter generator. Generating less heat, they will not trip the generator's breaker.

The substantial reduction in line noise that results from using PFC ballasts on the nearly pure power waveform of an inverter generator creates a new math when it comes to calculating the load you can put on a portable gas generator. In the past we had to de-rate portable generators because of the inherent short-comings of conventional generators when dealing with non-PFC electronic ballasts. The harmonic distortion created by non-PFC ballasts reacting poorly with the distorted power waveform of conventional generators limited the number of non-linear loads you could power on a portable generator to 60% of their rated capacity (4200 W on a 6500 W generator). But now, where inverter generators have virtually no inherent harmonic distortion nor sub-transient impedance and light manufacturers are making power factor correction available in smaller HMI, Kino, and some LED ballasts, this conventional wisdom regarding portable gas generators no longer holds true. According to the new math of low line noise, you can load an inverter generator to 100% capacity. For example, where before you could not operate more than a couple 1200 W HMIs with non-PFC ballasts on a conventional 6500 W generator because of the consequent harmonic distortion, now you can load an inverter 6500 W generator to capacity. And if the generator is one of our modified Honda EU7000is generators, you will be able to run a continuous load of up to 7500 W as long as your HMI, Kino, and LED ballasts are power factor corrected.

Now that low line noise enables the operation of more lights on portable generators, the last impediment to using them in motion picture production is the mechanical noise they make. A lot of filmmakers hesitate to use portable gas generators on their productions because it is almost impossible to record sound without picking up the noise of the generator. Even though the Honda EU7000is operates at 34 to 44 dBa at 50', you still need to take precautions. Whether you pick up generator noise on your audio tracks comes down to how you use it.

Just like you need to operate a blimped Crawford Studio unit off set, you will need to move a Honda EU7000is off set in order to not pick it up on your audio tracks. Unfortunately, a common problem with portable generators, even super quiet inverter generators, is that by the time you move them far enough off set that you don't hear them you have significant line loss (also referred to as "voltage drop") due to the long cable run, using regular 12- or 16-gauge cable, back to set. To the problem of line loss, you have the added problem that as you add load, the voltage drops on the portable generator. (It is not uncommon for a generator to drop 5 V to 10 V under full load.)

The combination of voltage drop on the generator and line loss on a long cable run can cause voltage to drop to the point where HMI and Kino ballasts cut out unexpectedly or won't strike at all. Low voltage can also cause problems such as reduced efficiency and excessive heat in equipment, unnecessary additional load on the generator, and a dramatic shift in the color temperature and in the output of lights. For these reasons, portable gas generators are typically operated too close to set where they are picked up on audio tracks. The trick to recording clean audio is to use a generator, like a Honda EU7000is, with a boost transformer/distro that will enable you to operate the generator at a distance without suffering from voltage drop. A transformer/distro can also be used to create a large 120 V circuit from the 240 V output of a portable generator, which makes it possible to power big lights, like 5K Molepars and M40 Arrimax HMIs on a 7500 W modified Honda EU7000is. That can eliminate the need for the diesel generators typically required to power these lights. And, because it provides you access to the full continuous rated power capacity of the generator in a single 120 V circuit, a transformer will also enable you to power more, smaller lights than you could without it.

In the next and final installment in this series on portable power on a budget, we will explore the benefits to using a small transformer/distro with portable generators. ■

**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.