BY RICHARD CADENA

Get your motor running—without voltage distortion

A FEW YEARS AGO, a group of us were in a warehouse at a large AV company in the Midwest learning about power factor and harmonics. We took an LED fixture that I knew had a low power factor, which means it generates harmonics, and connected it to a Fluke 43B power quality meter to measure the current distortion and harmonic content. In the process, I noticed a label on the fixtures that said the powerCON in and out power connectors could be used to daisy-chain up to eight fixtures. Since the fixture drew less than 1 A and we were on a 20 A circuit, eight fixtures draw well under the ampacity of the connectors and of the circuit. So, to me, the warning label sounded like a challenge.

> "What causes voltage distortion and why is it less prevalent than current distortion?"

Figure 1 – Warning: Never connect more fixtures than recommended by the manufacturer.

Don't try this at home

We began daisy-chaining the power feeding an increasing number of fixtures. We started with three or four and worked our way up to 12, 13, 14, 15…Dare we try 16? Yes, indeed. We ended up connecting 16 fixtures on a single power feed before we reached the ampacity of the circuit and stopped. It resulted in an interesting discovery that I've rarely seen—voltage distortion. The tops of the voltage sine wave began to flatten, a phenomenon known as "flat-topping."

Current distortion is common in live event production, but voltage distortion is much less common. What causes voltage distortion and why is it less prevalent than current distortion?

Current distortion and voltage distortion are closely related. The former is caused by non-linear loads, like switch-mode power supplies, that draw current in such a way that it changes the wave shape between the applied voltage and the current drawn.

In the case of the LEDs in the warehouse, the current was drawn in pulses. That's sometimes the case with LEDs because the power supply has smoothing capacitors whose job it is to help convert the incoming AC voltage to DC voltage. They are charged to a level close to the peak voltage, and when a capacitor in a circuit is charged, it passes no current unless the applied voltage is higher than the charge on the capacitor. In a power supply, that happens only during the peaks, which is why the current is drawn in pulses, as shown in **Figure 3**.

Usually, when harmonics are mentioned, it is the current, not the voltage, that is distorted. A non-linear load can generate a lot of harmonic current and not affect the voltage at all. However, if the harmonic current is high enough relative to the impedance or ampacity of the circuit, it can exacerbate the voltage drop, and that can distort the voltage waveform.

Every circuit has some voltage drop. If it becomes excessive (we measured a 27.5% voltage drop in the warehouse), then it causes a variety of issues, including the possibility of flat-topping the voltage waveform. It's caused by the higher-frequency harmonics, because the higher the frequency, the more the current tends to flow along the skin of the conductor rather than through the center of the conductor. This is known as the skin effect. That, in turn, increases the resistance of the conductors because there is less copper that is conducting, and that increases the resistance, and the increased resistance leads to greater voltage drop. Since the current

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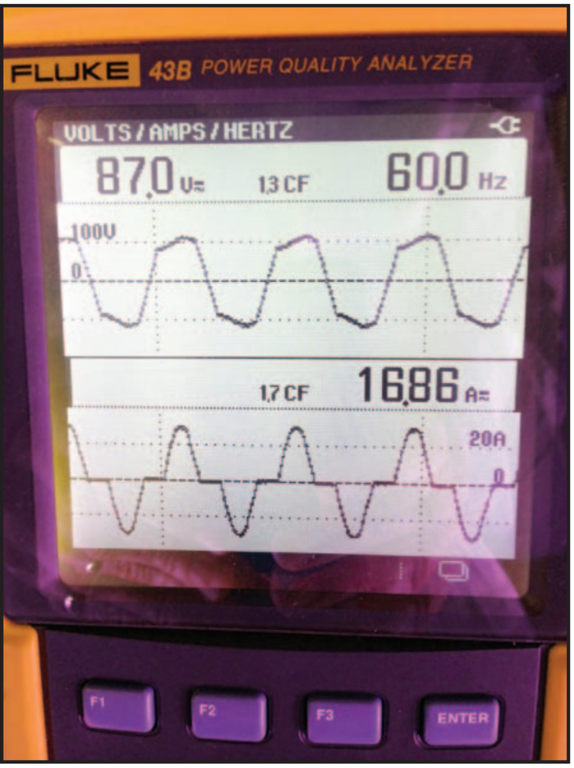

Figure 2 – When the number of fixtures connected exceeded the manufacturer's recommendation, the voltage waveform (top) began to flat-top.

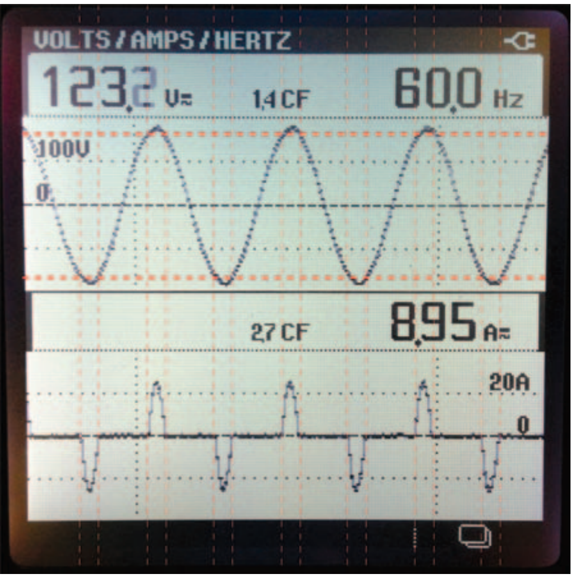

Figure 3 – When the applied voltage exceeds the charge on the capacitors, current flows, which is why current is drawn in pulses.

What are Harmonics?

In an electrical system, some devices can draw current in such a way that it produces a series of sine waves at frequencies that are whole number multiples of the power supply frequency. These sine waves are called harmonics, and there can be several dozens of them, depending on the load. If the fundamental frequency is 60 Hz, as it is in North America and other parts of the world that follow North American practices, then harmonics are multiples of 60; the second harmonic is 120 Hz, the third is 180 Hz, etc. If the fundamental frequency is 50 Hz, as it is in Europe, Australia, and other parts of the world that follow European practices, then harmonics are multiples of 50 Hz; the second harmonic is 100 Hz, the third is 150 Hz, etc. Harmonics are created by the connected load if it draws current in a waveform that differs from the voltage waveform supplying it, which makes it a non-linear load. A very distorted current will typically have components that reach up the 30th or 40th harmonic, and typically, the higher the harmonic number, the lower the amplitude.

Figure 4 – The harmonic content varies according to the connected load. Some loads can generate currents as high in frequency as the 30th or 40th harmonic, as shown in this bar graph.

When all of the harmonic components are summed in the circuit, it results in a complex waveform. If we could filter the pure sine waves out of the distorted waveform, we could see all of the harmonic components. The complex waveform is the sum of those harmonics.

is drawn in pulses, the voltage drop only occurs when current is flowing, which is around the peaks of the voltage waveform, and that results in "flat-topping," as illustrated in **Figure 2**.

The effects of harmonic current are well documented. They can cause enough current to flow in the neutral conductor of a 3-phase system, even if the phases are perfectly balanced, to overload it. Due to the skin effect, harmonic currents raise the temperature of every component in the path of the current, which can lead to nuisance tripping of circuit breakers, burned connectors and conductors, and they can shorten the life of feeder transformers and portable power generators. The higher frequencies can also produce more electromagnetic interference (EMI).

> **". . . the closer the voltage distortion is to the source of the power, the greater the risk of it spreading to other branch circuits."**

The effects of voltage distortion are less well documented, probably because it's rarer and its effects less obvious. If there is current distortion, then there may or may not be voltage distortion, but if there is voltage distortion, then you can bet that there is also current distortion, so all of the side effects of harmonics could be present. In addition, if there is voltage distortion with a large fifth harmonic component, then it can cause motors to rise in temperature and possibly overheat.

How do you know if there is voltage distortion? And if so, how do you know how large the fifth harmonic is?

The easiest way to find out is also the most expensive way, and that is to use a power quality meter. They can run several thousand dollars. Lacking that, you can use deductive reasoning and look for clues, like high neutral conductor current. If a high percentage of the connected load is non-linear devices, then that's another clue. If you measure the neutral feeder current and it's close to or higher than the phase conductor current, then there is high harmonic content. You can measure the voltage drop downstream of the distro and close to the loads, and if it's exceedingly high, then there could be voltage distortion. In that case, then motors in the vicinity of the voltage distortion should be closely monitored for overheating and they should probably be used sparingly or with a short duty cycle.

You can also shed load to reduce the voltage distortion. When the photos in the illustrations were taken, the voltage distortion didn't manifest itself until we connected a significant number of fixtures to the same branch circuit and loaded it to about 60% to 80% of its ampacity. The greatest risk of distorting the voltage waveform so much that it causes motors to overheat is when a circuit is very heavily loaded, and the closer the voltage distortion is to the source of the power, the greater the risk of it spreading to other branch circuits.

While it was fun to experiment with voltage distortion, it's never fun to experience it on a gig. So tread lightly on your power distribution system and you'll likely be okay. ■

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