BY RICHARD CADENA

Is my meter lying to me?

CHANCES ARE that if your meter, whether it's a voltmeter, an amp meter, or a multimeter, isn't labeled "true RMS," then it's probably an average-reading meter. That means it assumes the AC waveforms it reads are sine waves, and it bases all of its measurements on that assumption. The problem with average-reading meters is that they are only accurate if the AC waveform it is reading is a pure sine wave. If there is any waveform distortion, then an average-reading meter will yield errors, and the greater the distortion, the greater the reading error.

A true RMS reading digital meter, on the other hand, samples the waveform several hundred times per cycle and calculates the RMS value. So, assuming it's calibrated, it will be accurate for any waveform regardless of the distortion or harmonic content.

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We should know whether our meter is an average-reading meter or a true RMS reading meter because of the possibility of error. Typically, but not always, meters are marked somewhere on the front if they are true RMS. Lacking that, it's probably an average-reading meter. I have only seen one instance where it was not marked, and the specs said it was a true RMS meter. So, if it does not say true RMS on the meter, check the specs. I've also never seen a meter that says "average-reading" or anything similar, but if it's not a true RMS meter then it's an average-reading meter.

According to *Digital Multimeter Principles* by Glen A. Mazur (American Technical Publishers), an average responding meter will read about 40% low if the load draws current through a diode rectifier, which is how switch-mode power supplies (SMPS) work. In that case, for every 100 A of load we will read only 60 A, according to Mazur. Almost everything we use today in live event production, like LEDs, moving lights, digital amplifiers, projectors, etc., have switch-mode power supplies, and there is almost always some degree of current distortion in a system. Many SMPSs, but not all, correct that distortion, and if it is power factor corrected, then the current is drawn in almost a pure sine wave.

Without power factor correction, the current is drawn through the power supply in pulses, which are caused by the interaction between filtering capacitors and the voltage applied to them. Some of these pulses can be very sharp and peaked. The resulting distorted waveform contains harmonics, which can cause several issues of concern, including high neutral feeder current even in a balanced 3-phase system. Since the neutral feeder conductor is not protected by a circuit breaker or fuse, it's critical to ensure that it not overloaded, so it should be closely monitored any time a power distribution system is heavily loaded. How do we monitor it? With a meter, of course. But what if that meter yields inaccurate information? That's the dilemma we face using an average-reading meter.

If your meter isn't marked "True RMS," it's likely an average-reading meter.

How do we know if we have harmonics? (Hint: We probably do.) The only way to know for sure, as far as I know, is to use a power quality meter, which is very expensive and very rare for the average stage electrician to have. The next best option is to gather clues and piece them together to make an educated guess about the harmonic content in a power distribution system.

The first clue that we might have harmonics is to look at the equipment schedule. If we have LEDs, moving lights, computers or devices with computer chips, like consoles, variable speed motors, or dimmers, then we likely have some degree of harmonic distortion. (If you read that last sentence and thought to yourself, "That's pretty much everything I ever use on a show," then you're on to something.) Typically, it's not a matter of whether we have harmonics but how much harmonic distortion you have compared to the overall load.

If we have a balanced 3-phase load, then the second clue is that there is a lot of current on the neutral feeder conductor. In a balanced 3-phase system with no harmonics there will be no current in the neutral feeder conductor. In an unbalanced 3-phase system, the neutral conductor will carry the unbalanced return current. It may seem like an easy matter to meter the neutral to find out, except for one thing; an average-reading meter will read incorrectly if there is high harmonic content. According to Mazur, an average responding meter will read 5% to 30% low for 3-phase diode rectified loads, which is what the neutral feeder conductor carries when harmonics are present in the system. So, whatever reading we get with the average-reading meter, multiplying it by about 1.43 will give you a rough estimate of worst-case scenario.

> **"If we have reason to believe there is high harmonic content, then we would be wise to question the readings of an average-responding meter."**

Another clue that there is high harmonic content is that the components of our power distribution system seem to run hotter than normal. If we use an infrared camera, like a Flir One, then it's easy to measure the surface temperature of conductors, connectors, circuit breakers, dimmers, and more, and it's easy to see hot spots that could potentially be a problem. (See Michael Matthews' article "Looking for Some Hot Stuff, Baby!" in the Summer 2020 *Protocol*.) Also, if circuit breakers seem to be tripping for no good reason, that could be caused by harmonics.

If we have reason to believe there is high harmonic content, then we would be wise to question the readings of an average-responding meter. In the long run, we're better served by replacing that meter with a true RMS meter. There are some that are reasonably priced, and we are only as good as the tools we use. ■

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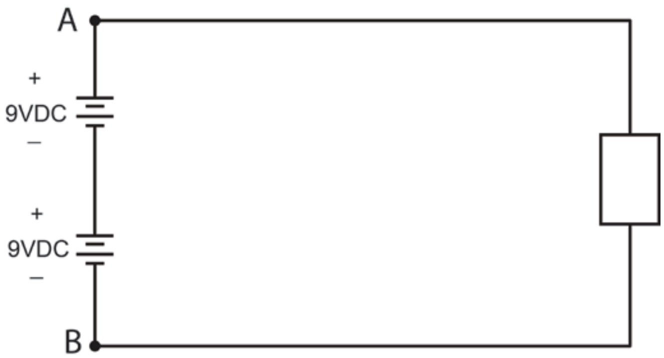
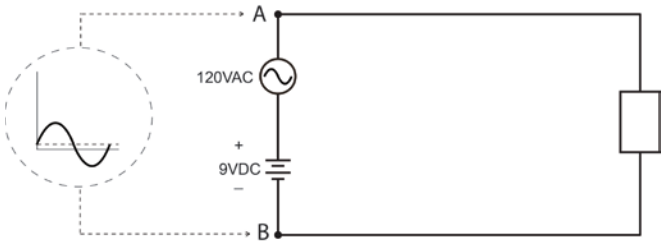
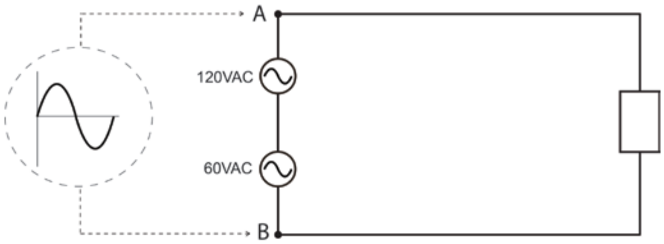


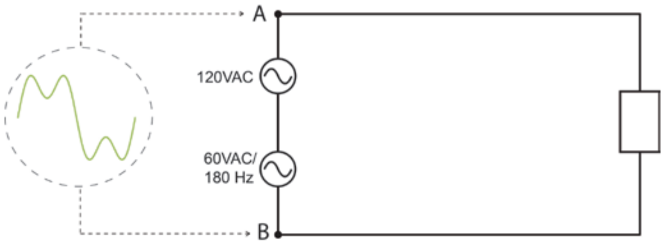
Two power supplies in series sum across the load. In this case, two 9VDC batteries apply 18VDC to the load.



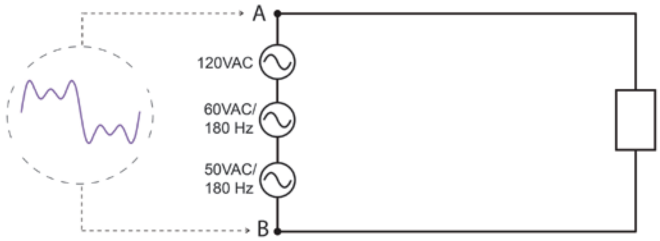
If one of the supplies is AC and the other DC, then the sum is a sine wave with a DC offset. In this case, the 120 VAC sine wave has a 9 VDC offset.



Two AC power supplies with the same frequency but different amplitudes result in the RMS sum. In this case, a 120 VAC sine wave combines with a 60 VAC sine wave to produce a 180 VAC sine wave.



If one of the supplies is 120 VAC at 60 Hz and the other is 60 VAC at 180 Hz, the sum is a distorted waveform (not a sine wave) as shown in the inset. This complex waveform contains both the 60 Hz fundamental frequency and the third harmonic (180 Hz).



The more harmonics added to the system, the more distorted the resulting waveform. Conversely, a more distorted current waveform contains more harmonics.

Harmonics

Suppose we had two DC power supplies, like two 9-volt batteries, and we wired them in series as shown in the illustration. If we measured the voltage from point A to point B, the meter will read 18 V.

Now suppose we pressed a magic button on one of the supplies and it turned into a 120-volt AC supply with a frequency of 60 Hz. If the meter is still connected to the same two terminals, then the voltages will sum and the result will be a 120 V sine wave with an offset of 9 V, as shown in the second illustration.

If we could press another button and turn the second supply into a 60-volt AC supply with a frequency of 60 Hz, then the voltage across the same two terminals would be 180 VAC_{RMS}. Since the two sines are in phase, we're just summing them, resulting in a single sine wave of greater amplitude than either of the two. The amplitude is the sum of the RMS values, which in this case is 180 V.

Now let's change the frequency of the second power supply. Instead of 60 Hz, we'll make it a whole number multiple of 60, like 180 Hz (3 x 60 = 180). The two sine waves will still sum when we look across the terminals, but the result is no longer a sine wave; it's starting to resemble a square wave with big dips in the positive and negative halves as shown in the next illustration. If we add a third AC supply with a lower amplitude and a frequency of 300 Hz (5 x 60), then the sum of the three sine waves would be even more distorted. The second and third power supplies are generating harmonics of the 60 Hz fundamental frequency, and the more harmonics we add, the more distorted the resulting waveform.

By the same token, if we start with a distorted waveform, we can filter out the pure sine waves that make up that particular waveform. The frequencies of those sine waves will be whole number multiples of the fundamental frequency and the amplitudes will be gradually decreasing with the increasing frequencies. When we add sine waves together to form a distorted waveform, that's wave synthesis, and when we filter them out of a distorted waveform, that's the Fourier analysis, which is a mathematical method of analyzing complex waveforms.

When a non-linear load, like a non-power factor corrected LED fixture is connected to a supply and it draws current in a distorted waveform, that current contains all of those pure sinewaves of different frequencies and amplitudes. Those are harmonics and they can cause the neutral conductor of a 3-phase system to carry more current than any of the 3-phase conductors, which can lead to overloading. They also produce more heat than the fundamental current because of the skin effect, which is the principle that higher frequency currents tend to travel along the skin of a conductor rather than through the center of the conductor. That means there is less copper conducting, which translates to higher resistance and higher heat for the same amount of current. And more to the point of this article, average-reading meters only read the fundamental frequency and not the harmonics, leading to reading errors; the greater the harmonic distortion, the greater the reading error.