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Use PFC To Get More Power Out Of Your Wall Socket

A GOOD FRIEND of mine in the professional audio business recently said that audio amplifiers with power factor correction (PFC) can draw much more power from a #5-20 wall outlet than amps that don't have PFC. The limit, of course, is the tripping point of the thermo-magnetic circuit breaker. This prompted me to ask how the thermal-magnetic circuit breaker works. Most of this we know already.

A LITTLE REVIEW

The thermal-magnetic circuit breaker passes the current through a few turns of wire around a solenoid. When the magnetomotive force (MMF) is high enough, the solenoid pulls down a trigger mechanism that trips the circuit breaker and interrupts the circuit. This usually occurs at a current rating much higher than the rated current of the breaker. Also, a thermal mechanism in the breaker would trip if it gets too hot. It's usually a bimetallic contact arranged to trip the mechanism and open the breaker when it has enough current flowing through it to hit the appropriate temperature.

The solenoid sees MMF just like a rotating disc power meter *(see "PFC: A Little Old-School Knowledge," parts 1 and 2, at www.electronicdesign.com)*. The bimetallic contact sees rms heating, which is a product of the square of the rms current flowing through the breaker and the constant resistance of the strip. Once this device gets hot enough, it trips the breaker. The important part to understand is that there are two different mechanisms at play. The solenoid works on a half-cycle average of the current, and the bimetallic strip works on I^2*R heating, where I is the rms current through the element.

First we need to understand the waveforms and the mechanics of what is going on. The big, conventional class AB audio amplifier without PFC will have low-leakage inductance transformers for isolation and classical rectifiers to make the $\pm V_{CC}$ rails to the power amp.

The line current waveform looks like that of the classical rectifier—a narrow peak of current in phase with the peak of the ac line waveform. The only attribute of the waveform that changes with load is the amplitude of the peak. It would seem that my friend was right. If we assume the overload condition is reasonable, like a band playing too loud and blowing a 50-A fuse (as Mick Jagger sang in "You Can't Always Get What You Want"), it is likely that the bimetallic strip heating will trip the breaker and not the MMF from the solenoid.

BACK TO THE BENCH

Then I wondered if I had anything in my junk box that I could use to test a breaker. (Also, where's my *Let It Bleed* CD?) What if I made a load with a classical rectifier and then another load with a plain old resistor? I could then hook these up to my ac source with the breaker in series and see the current and delay time for the breaker to trip. Sounds fun!

I built up a classical rectifier load, with a 16-Ω power resistor (8-Ω audio loads in series) with a bridge rectifier and a 12,000-µF, 250-V capacitor. The plain old resistive load was just the 16-Ω non-inductive audio loads. The breaker was a basic thermo-magnetic breaker, rated for 3 A.

When I applied power, I noticed that after 13 seconds, the breaker would trip when delivering 5 A rms to the load—hardly a 50-A fuse! This was repeatable to within 0.5 seconds starting with a fresh closure on a cool, rested breaker. The peak of this current as measured on an oscilloscope was around 7.1 A, consistent with the crest factor we'd expect from a sinusoid. If the breaker isn't rested, it trips faster—yet another hint that MMF isn't causing the trip, but thermal response.

I then switched over the classical rectifier load. Setting up the ac source to supply the same current took a little adjustment, but I confirmed the same overcurrent and timing as above. In other words, the classical rectifier also trips in 13 seconds at a 5-A rms load starting from a cool, rested, open position. The peak of this current was 20 A, and again, it was a narrow pulse, in phase with the line voltage waveform. Clearly, there were plenty of odd harmonics. Looking at the currents alone, this result is peculiar. It's the same current. That doesn't agree with my friend's statement—or does it?

THE FINAL ANALYSIS

Now for the fun part. With the plain old resistive load, at 5-A rms line current, my true rms, real power meter measures 404 W rms. Over several repetitions, this was measured within 5 W. With the classical rectifier load and 5-A rms line current, my true rms power meter measures 225 W rms, repeatable to within 3 W. My friend was right. The reactive harmonics that contribute to all of that I rms heating in the bimetallic contactor aren't supplying much power to the load due to their phase relationships.

PFC stage in the power amplifier would provide a current waveform of the same shape as the line voltage, ideally a sinusoid. Assuming reasonable conversion efficiencies, this amplifier would be able to play louder from a standard outlet than its non-PFC counterpart of similar output power rating (all other things the same). This is due to the absence of the harmonics in the current waveform.

If the trip mechanism were purely magnetic, based on MMF alone, without a bimetallic thermal strip, PFC wouldn't matter at all. But at light overload condition, the bimetallic strip causes the breaker to trip, making it the limiting factor in this example. It turns out my friend was right, and my Rolling Stones CD still sounds good.

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