How does high-efficiency lighting affect power quality?

Application Note

By Chuck Newcombe

I recently wrote about the imminent disappearance of the tungsten filament lightbulb from your local stores. My focus in “Say Goodbye to the Incandescent Lightbulb” was on the tungsten filament, its inefficient use of power in generating light, and the reasons for its relatively short life. Now I’d like to focus on some of the properties of the high-efficiency bulbs we’re going to be buying.

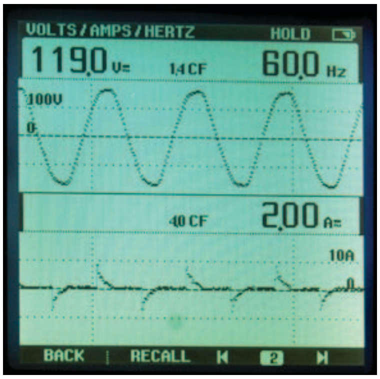
First is cost

It’s hard to gauge the true cost of compact fluorescent lamps (CFLs) because of the incentive subsidies currently being offered by utilities, but suffice it to say that a CFL generally costs significantly more to manufacture and buy than the equivalent incandescent lamp. The packaging for CFLs typically shows a comparison of light output in lumens vs. power consumed in watts, as well as color temperature information. The comparison for one 120 V, 800 Lumen (60-watt incandescent equivalent) CFL indicates that it will use one-fourth the energy (15 watts), and that it is guaranteed to last 5 years when used for 3 hours a day. It is suggested that this is eight times the life of the equivalent incandescent lamp, and that with the savings in power used the overall cost of ownership will be lower.

The least expensive CFLs have some disadvantages with respect to incandescent units. They cannot be used with dimmer controls. There are now dimmable CFLs offered, but these come at a premium price. Also, the first CFLs generated high-frequency noise that could affect am radio reception. This problem has been reduced by later units that incorporate noise filter technology.

How about the power quality effects of CFLs?

I recently ran a series of tests on energy-saving CFL and LED replacement lamps to see how they compare as loads relative to the incandescent bulbs they are to replace. Suffice it to say that they are nonlinear in their use of current, gulping their power in short bursts. The following three figures show the current used by a 60-watt-equivalent



CFL current harmonics. There is 76 % total harmonic distortion (THD) in this current. The total harmonic current reading (1.77 A) is much greater than the fundamental 60 Hz current (1.15 A). The graph shows that harmonics up to the 51st (3,060 Hz) are present due to the nonlinear current flow.

CFL power statistics. The kW reading is much lower than the kVA reading because current harmonics cause the total power factor (PF) to be much lower than the displacement power factor (DPF). DPF indicates the slight lag of fundamental current from the voltage.

CFL voltage and current. While the voltage is a sine wave, the current is used in narrow pulses. As a result the crest factor (CF) reading for the current is 4.0, meaning the peak current is 4 times the rms value rather than the desired 1.4 of an undistorted sine wave, as appears in the voltage above.

CFL, the harmonic spectrum of that current, and the watts vs. volt-amp efficiency that results in a power factor (PF) of 0.55. The 60-watt incandescent bulb's linear load would have a power factor near 1.0. (See "What if the power factor is lower than 1.0?" for a detailed explanation.)

Note: All current and power readings are 10 times the actual because of my measurement setup using 10 turns in the current measuring loop, while the harmonic percentages and power factor numbers are correct as shown.

The above performance information is based on a fully warmed-up CFL. At turn on, the typical CFL will gradually approach full brightness after a minute or so. You can buy instant-start CFLs that draw more power (as much as six times the running current) for 30 seconds or so, and achieve near-full brightness immediately after turn on. The running current of these bulbs after the start-up phase is similar to the above results.

How about those LEDs?

I also tested a replacement lamp that uses LEDs instead of fluorescent technology. The equivalent of a 60-watt incandescent lamp used only 14 watts, with a total power factor of about 0.8. Harmonic current distortion was about 55 %. The LED unit I tested was both dimmable and instant-on. While these units present less of a power quality problem, they are still much more expensive than the equivalent CFL, so I think it will be a while before they become commonplace.

What is the overall effect of residential nonlinear loads on the utilities?

The bad news for electrical utilities is that they are seeing a steadily rising occurrence of nonlinear loads on their distribution systems. This hasn't yet become a major problem with CFLs because total substitution of incandescent lighting by CFLs would result in an overall 75 % reduction in power load.

The utilities won't see a corresponding reduction in overall demand, however. The sneak problem is this: incandescent lamps are linear loads generating few harmonics, thus keeping power factor high. The new nonlinear CFL loads will cause the power factor to be lower because of the harmonic currents generated by the new lamps. Lower power factor may result in a requirement for oversized distribution equipment and wiring in order to deliver power to a customer.

I believe that the net effect is that it is still beneficial for the utilities to promote the use of nonlinear lighting technology.

Several months ago I wrote a column that investigated the present state of harmonics on a utility's power distribution network in my neighborhood. My tests showed that the neutral current of the three-phase lines back to my nearest substation was dominated by third harmonic current, rather than the classical fundamental unbalance of the phases, so my local utility is already seeing the effect of electronic nonlinear loads in residential distribution: they reduce the usable power supply.

Read about the present state on a utility's neighborhood power distribution network at www.fluke.com/AboutHarmonics.

Summing it up

I think we can conclude that CFLs and LEDs will be significant in our future lighting. The technology advances made in recent years, as well as the promotion by utilities and governmental agencies, makes this an easy call.

What if the power factor is lower than 1.0?

In residential service the utility charges for the power used in kilowatts (kW). If the power factor is 1.0, the kilovolts ampere (kVA) equal the kW and transmission is most efficient.

When the power factor is much lower than 1.0, then the kVA is much higher than the kW, and the system must carry more current to deliver billable power to the customer. This results in greater losses in transmission due to the higher current, and the need for oversized equipment, for which there is no compensation.

In industrial service, the utility contracts can charge a demand penalty to compensate for these losses.

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