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Innovating Reliable Power

Improving Power Quality with Power Factor Correction

By Mel Berman

The ideal Power Factor (PF) for electric or electronic devices that operate from the AC power main is unity or 1.0. Products with power factors that are much lower than 1.0 have a negative effect on the AC power line's quality as well as drawing more electric current than is necessary, thus costing more to operate.

Since switchmode power supplies without Power Factor Correction (PFC) tend to draw the AC line current in a non-linear fashion, many unwanted harmonic currents are generated and reflected back on the AC power lines, degrading the power quality. For example, the first harmonic is the primary input frequency, typically 50 Hz for the EU (European Union) countries. The third harmonic is 150 Hz, and the 39^{th} harmonic is 1,950 Hz. These unwanted harmonic currents have a direct relationship to the Power Factor of switchmode power supplies that power electronic equipment.

An important reason to have PFC within a power supply is to comply with international regulations, especially if you intend to sell your equipment in Europe. Since 2001, the European Union (EU) established limits on harmonic currents that can appear on the mains (AC line) of switchmode power supplies. Today, the most important regulation is the "European Norm" EN61000-3-2. This regulation applies to power supplies with input power of 75 watts or greater, and that pull up to 16 amps off the mains. It sets severe limits on the harmonic currents up to the 39^{th}, when measured at the input of switchmode power supplies. Power supplies with PFC circuits that meet EN61000-3-2 inherently have high power factors that are typically 0.97 or better.

Here in America, on September 30, 2008, the U.S. ENERGY STAR Solid-State Lighting (SSL) Luminaire program went into effect, which established minimum power factors of ≥ 0.90 for new commercial illumination fixtures that employ LEDs (Light Emitting Diodes).

What is Power Factor Correction (PFC)?

Power Factor (PF) is technically the ratio of real power consumed to the apparent power (Volts-RMS x Amps-RMS), and is expressed as a decimal fraction between 0 and 1. PF is traditionally known as the phase difference between sinusoidal voltage and current waveforms. When the AC load is partly capacitive or inductive, the current waveform is out of phase with the voltage (Fig. 1). This requires additional AC current to be generated which isn't consumed by the load, creating I^2R losses in the power lines.

An electric motor is inductive, especially when it is starting. The current waveform lags behind the voltage waveform, dropping the PF to well below 1 (similar to Fig. 1). This is why many motors have "starting" capacitors installed to counteract the inductance, and therefore correct the PF during motor startup.

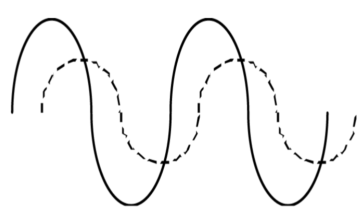

Figure 1. Voltage and current waveforms are sinusoidal but out-of-phase; PF <1.

A simple resistive load has the highest PF of 1. An AC voltage across the resistor causes an AC current which is identical to and in-phase with the voltage waveform (Fig. 2).

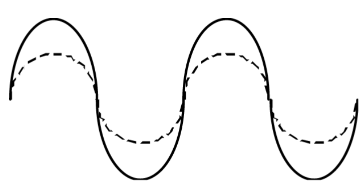

Figure 2. Voltage and Current waveforms are sinusoidal and in-phase; PF=1.

A switchmode power supply when viewed as an AC load is neither capacitive nor inductive, but non-linear. A switchmode supply conducts current in short pulses or spikes that are in-phase with the line voltage (Fig. 3). The product of "Volts-RMS x Amps-RMS" is considerably higher than the real power consumed, and thus the PF is much less than 1, typically around 0.65 or less.

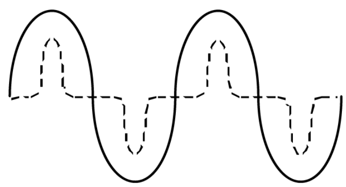

Figure 3. Voltage waveform is sinusoidal, current waveform is non-sinusoidal but in-phase; PF<1.

For example, an AC-DC switchmode power supply without any PFC may draw approximately 950 watts from a typical 115VAC wall socket protected by a 15A circuit breaker before exceeding the UL mandated limit of 12A. However, a simple AC load like a toaster can draw almost 1400 watts. The difference between the two is due to the higher Power Factor (PF) of the toaster, which presents a resistive load to the power line. If we correct the Power Factor of the switchmode supply, it can then draw about as much power as the toaster, allowing it to provide more output power to its load from the same 115VAC/15A wall socket.

Improving the Power Factor

Low Power Factors can be improved via Power Factor Correction (PFC) circuits. The types used for switchmode power supplies "smooth out" the pulsating AC current, lowering its RMS value, improving the PF and reducing the chances of a circuit breaker tripping. There are two basic types of PFC: Active and Passive. Active PFC is more effective, a bit more expensive, generally integrated into the switchmode power supply, and can achieve a PF of about 0.98 or better. Passive PFC is less expensive and typically corrects the PF to about 0.85.

Harvesting Additional Output Power

To determine just how much more power is available from the AC line and a power supply with PFC, the user needs to understand the following equation, which defines the amount of output power (Pout) available from a switchmode supply:

$$\mathbf{Pout = V_{L\text{-}RMS} \times I_{L\text{-}RMS} \times PF \times Eff}$$

For example, UL limits a system's line current to 80% of the circuit breaker's rating. For a typical 15A breaker 12-Amps is the maximum allowed and the best-case power available is therefore 120VAC x 12A = 1440 Watts. Referring to the above equation, here are two examples of supplies with different power factors:

- A switch-mode supply with 0.65 PF and 85% efficiency can only deliver (120 x 12 x 0.65 x 0.85) = 796 Watts (Pout).

- However, if the power factor is corrected to 0.98, the same power supply can now deliver (120 x 12 x 0.98 x 0.85) = 1200 Watts (Pout), a 51% increase.

In Summary

"Power Line Harmonics" are created whenever the line current is not a pure sinewave, as is the case with a switchmode power supply's input which tends to have "pulsed" currents (Fig 3). Measuring power line harmonics is a mathematical means to describe a complex waveform's Power Factor by resolving it into a fundamental frequency and its many harmonics. The harmonic currents do not contribute to the output load power and will cause poor power quality, unwanted heating in the wall socket, wiring, circuit breaker, and distribution transformers.

PFC significantly reduces harmonics, resulting in almost a pure "fundamental" current frequency that will be in-phase with the voltage waveform (Fig. 2). International regulations dictate the substantial attenuation of harmonic currents. The vast majority of AC-DC power supplies manufactured by TDK-Lambda employ active PFC, is in accordance with EN61000-3-2 and provides typical power factors in the range of 0.97 to 0.99. More information on this subject can be found at www.us.tdk-lambda.com/lp .

Typical 1000-Watt Switchmode Power Supply with PFC (meets EN61000-3-2)
Power Factor = 0.98, Efficiency = 88%

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