

App Note 513 - Power Factor Correction

An off-line switch-mode power supply can draw approximately 950 Watts from a typical 110VAC wall socket protected by a 15A circuit breaker before exceeding the UL mandated limit. A simple load like a toaster can draw almost 1400 Watts. The difference between the two is due to the low power factor (PF) of the switch-mode power supply. If we correct the PF the switch-mode supply can draw about as much power as the toaster can, allowing it to power a larger load from the same 110VAC 15A wall socket.

What is Power Factor Correction (PFC)?

Power factor (PF) is technically the ratio of real power consumed to 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 (Figure 1b). This requires additional AC current to be generated which isn't consumed by the load, creating I^2R losses in power cables.

A simple resistor has the highest PF - one. An AC voltage across the resistor causes an AC current which is identical to and in phase with the voltage waveform (see Figure 1a).

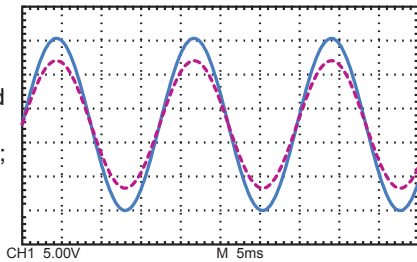


Figure 1a. Voltage and Current waveforms are sinusoidal and in phase; PF=1.

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. This is why many motors have 'starting' capacitors fitted to counteract the inductance, and therefore correct the PF during motor startup.

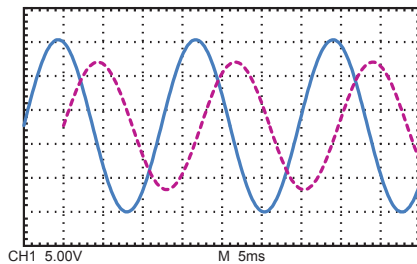


Figure 1b. Voltage and current waveforms are sinusoidal but out of phase; PF < 1.

A switch-mode power supply when viewed as an AC load, is neither capacitive nor inductive, but non-linear. A switch-mode supply conducts current in short pulses that are in phase with the Line Voltage. The product of (volts RMS x amps RMS) is considerably higher than the real power consumed, and thus the PF is less than 1, typically around 0.65.

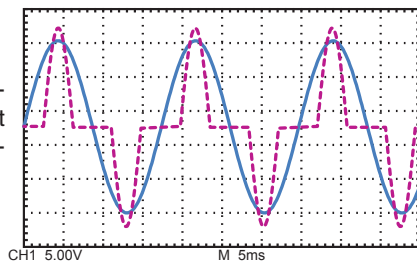


Figure 1c. Voltage waveform is sinusoidal, current waveform is nonsinusoidal but in phase; PF < 1.

Improving Power Factor

Non-unity PF can be improved with power factor correctors (PFC). 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, more expensive, generally integrated with the switch-mode power supply, and can achieve about 0.98PF. Passive PFC is more reliable, inexpensive, and typically corrects to about 0.90.

Harvesting Additional Output Power

To determine just how much more power is available with PFC, the user needs to understand the following equation, which defines the amount of power available from the supply:

$$P_{out} = V_L(RMS) \times I_L(RMS) \times PF \times Eff \dots \dots \dots \text{equation 1}$$

For example, UL limits a system's line current to 80% of the circuit breaker's rating. For a typical 15A breaker 12A is the maximum allowed, and the best-case power available is (120VAC x 12A) = 1440Watts. A switch-mode supply with 85% efficiency and 0.65PF can only deliver (120 x 12 x 0.65 x 0.85) = 796Watts. 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) = 1200Watts, a 51% increase.

TDK-Lambda's ALE High Voltage products feature both active PFC and passive PFC dependent on the power level of the unit. The OEM series supplies (500A, 102A, 152A and 202A) are available with active PFC (optional on 500A through 152A, standard on 202A) which corrects the PF to 0.98 from the non-PFC figure of 0.65. This can result in a line current reduction of greater than 60% for the same supply output power. High power supplies with 3 phase inputs use passive PFC to give a typical PF of 0.8 to 0.9. Passive PFC is much simpler to implement than active PFC particularly at the higher power levels associated with 3 phase supplies.

Reducing Line Harmonics

"Line harmonics" are created when the line current is not a pure sine wave, as is the case with a switch-mode power supply's input 'pulsed' currents. Measuring line harmonics is simply a mathematical means to describe a complex waveform's PF by resolving it into a fundamental frequency and many harmonics. Harmonic currents do not contribute to load power, but cause unwanted heating in wiring, circuit breaker, and distribution transformer. Active PFC can eliminate harmonics, leaving just the pure 'fundamental' frequency.

Summary

Switch-mode power supplies inherently conduct line current in short pulses, which is not desirable. This less than optimum current can be quantified by measuring its PF or by its harmonic content. Poor PF causes unwanted heating in external AC circuits, which can be reduced by correcting the PF. The ALE power supply range is available with either active electronic PFC (PF ~ 0.98) or passive PFC (PF ~0.8 to 0.9).

If you have any questions or comments regarding this or any of our Application Notes or products, please contact Andy Tydeman at the factory, we are here to help.

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