

NEW POWER REGULATIONS BRING POWER-FACTOR CORRECTION TO LOWER-POWER SUPPLIES

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Until recently, power factor and PFC (power-factor-correction) circuits were of concern only for utilities and manufacturers of motors. Utilities have for years specified the power-factor performance of large inductive motors. The utilities also generally can charge industrial customers for reactive-power consumption. However, residential customers are starting to introduce more reactive-power loads into the mix as energy-efficient lights, such as CFLs (compact fluorescent lights) and LED-based lights containing their own ac/dc lighting ballasts, begin to emerge. As a result, power factor has moved from the realm of large-scale industrial motors down to that of consumer electronics.

WITH THE INTRODUCTION OF NEW POWER-SUPPLY SPECIFICATIONS FROM ENERGY STAR, COMPUTER POWER SUPPLIES AS LOW AS 75W AND SOLID-STATE LIGHTS AS LOW AS 5W MUST MEET MINIMUM POWER FACTORS, MAKING POWER FACTOR A CONCERN FOR MOST ELECTRONIC EQUIPMENT THAT USES AC-LINE POWER.

Power factor is the ratio of real power to apparent power. When both current and voltage are sinusoidal and in-phase, the power factor is one. If they are sinusoidal but not in-phase, then the power factor is the cosine of the phase angle. Purely sinusoidal current and voltage waveforms occur when the load comprises resistive, capacitive, and inductive elements that are all linear.

In a purely resistive load, real power is the same as apparent power, and the power factor is one. When the load has inductance or capacitance, however, the apparent power is greater than the real power because the capacitance and inductance introduce a phase lag be-

tween the current and the voltage. Although utilities currently charge residential customers only for the real power they consume, the utilities must add power to support the out-of-phase current and voltage. The additional power is wasted in the form of resistive losses on the grid's transmission lines. Because these losses increase as the square of the current increases, losses due to low power factor can quickly add up.

The ac line sees an SMPS (switched-mode power supply) as a nonsinusoidal, nonlinear impedance (Figure 1). Figure 2 shows the voltage and current for the circuit of Figure 1. To more closely follow the input voltage and avoid



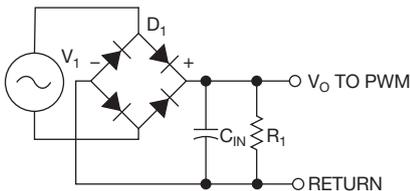


Figure 1 The SMPS presents a nonlinear load to the ac-power line.

sharp current spikes, the capacitor must charge over the entire positive portion of the cycle. In addition to upping the power factor closer to one, this shaping of the current allows for the use of a smaller capacitor and avoids the creation of harmonic noise, thus reducing THD (total harmonic distortion). This compensating additional circuitry is the PFC circuit. Energy-efficiency specifications regulate both THD and power factor as part of the power-factor specification.

Note that PFCs decrease rather than increase power-supply efficiency. “Power-supply designers are only moving to incorporating improved power factor in their supplies because of government mandates,” says Steve Mappus,

AT A GLANCE

Agencies such as Energy Star and Climate Savers are setting power factors for relatively low-power consumer devices and computer servers.

PFC (power-factor correction) does not improve a supply’s efficiency.

Digital PFC is becoming a cost-effective design approach, especially for designs already containing a DSP or a microcontroller.

a systems engineer in the High Power Solutions group at Fairchild. The utility companies are the immediate beneficiaries of improved power factor, but consumers benefit downstream because utilities need not build additional power plants, holding pollution and carbon emissions in check.

Many topologies and approaches exist for enabling PFC (see sidebar “Utilities and PFC”). In general, PFC is either passive or active. Government and industry regulations specify only the power factor and the THD, leaving the

decision about whether to use a passive or an active circuit to the design engineer (tables 1 through 3).

Passive PFC is a simple, relatively inexpensive approach, but it has drawbacks. Chief among them is that it’s difficult, although not impossible, to get a power factor of more than 0.7, and the trend in global regulations is toward power factors of 0.9 and higher. Another difficulty with passive PFC is that the capacitors go directly on the ac line, necessitating capacitor ratings of 400V or higher. This requirement makes the use of electrolytic capacitors the most common approach. Electrolytic capacitors’ lifetime drops with higher temperatures, so you must derate the capacitor if your system will need to work in a hot environment. To derate it, you must either choose a higher temperature, more-expensive capacitor or allow for a shorter capacitor lifetime. Another drawback with passive PFC

TABLE 1 CLIMATE SAVERS CRITERIA FOR MULTI-OUTPUT POWER-SUPPLY UNITS

Loading condition (%)	Bronze Level		Silver Level		Gold Level	
	Efficiency (%)	Power factor	Efficiency (%)	Power factor	Efficiency (%)	Power factor
20	82	0.8	85	0.8	87	0.8
50	85	0.9	88	0.9	90	0.9
100	82	0.95	85	0.95	87	0.95

Source: Climate Savers, www.climatesaverscomputing.org/tech-specs

TABLE 2 LED-LIGHTING POWER-FACTOR CRITERIA

Equipment	Power factor
Solid-state-lighting luminaires	
Residential	≥0.7
Commercial	≥0.9
Integral LED lamps	≥0.7

Sources:

http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/lighting/ESIntegralLampsCriteria_Draft1.pdf
http://www.energystar.gov/ia/partners/product_specs/program_reqs/SSL_prog_req_V1.1.pdf

TABLE 3 ENERGY STAR POWER-FACTOR REQUIREMENTS FOR COMPUTER-SERVER POWER SUPPLIES

Type	Rated output power	10% load		20% load		50% load		100% load	
		Power factor	Efficiency (%)						
AC/DC multi-output	All output levels	NA	N/A	0.8	85	0.9	88	0.95	85
AC/DC single-output	≤500W	NA	80	0.8	88	0.9	92	0.95	88
	500 to 1000W	0.65	80	0.8	88	0.9	92	0.95	88
	>1000W	0.8	80	0.9	88	0.9	92	0.95	88

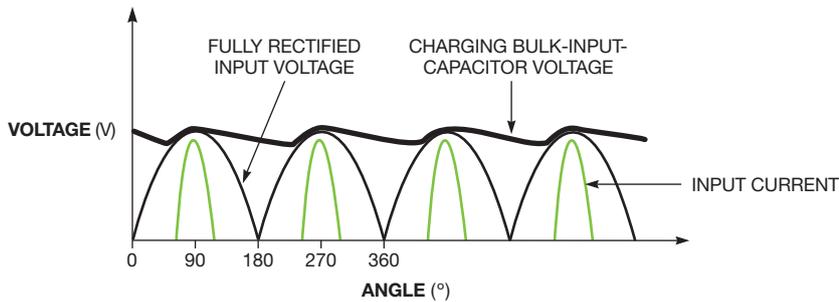


Figure 2 Superimposing the current over the voltage for the circuit in Figure 1 shows the need for a PFC to shape the current.

is that its voltage output is unregulated as it feeds into the dc/dc-conversion stage. For these reasons, the trend is toward active PFC, usually in the form of a boost-converter circuit between the bridge rectifier and the storage capacitor.

The most common configurations for an ac/dc power supply with PFC are two-stage and single-stage designs. In a two-stage design, the ac line feeds into an ac/dc converter, usually comprising a bridge rectifier feeding into a capacitor whose output is usually full of second-harmonic ripple. A dc/dc converter follows the ac/dc converter to provide electrical isolation and voltage regulation. This approach keeps the two stages separate, is easy to troubleshoot, and is simple. However, the double conversion is less efficient, and costs are higher because of the need for two stages. As PFC becomes more prevalent, single-stage PFC is becoming more common.

Kishore Manghnani, vice president of Green Technology for Marvell, argues that single-stage power-converter/PFC ICs are the best design approaches for LED lighting. “With two-stage you end up using two separate chips—one for PFC and the other for the LED-driver circuit, which includes dimming and the TRIAC [triode-alternating-current-switch] interface,” he says. “In a single-stage converter/PFC chip, you need no additional components: You put the LED driver and the PFC all in one chip.” You might wonder whether you can use cheaper passive PFC, given that cost is a pacing item in LED lighting, but Manghnani advises against this approach. “The biggest advantage of active PFC is that you can use a low-voltage capacitor,” he says. “In passive PFC, the capacitor must support 400V. In the active single-stage [approach], the capacitor is only 40V. Plus, the life-

time of the capacitor [for the same cost] could be four to five times longer.”

Currently, Energy Star’s draft proposal for energy-efficient luminaires calls for a power factor of 0.7 in residential lighting and 0.9 in commercial, but Marvell argues that the power factor for LED lighting should be 0.9 for all lights with wattage higher than 5W, which is currently the specification in Europe and Korea. “The United States is a bit behind in this area,” Manghnani says. “Europe and Korea require lighting power to be more than 0.9. It doesn’t cost anything extra, so why not add it?”

The mandate for minimum power-factor requirements comes at the same time as the industry is imposing increasingly tight efficiency standards on power supplies, causing a double whammy on designers, who must strive for more stringent efficiencies as power factor creeps up. Thus, research is ongoing on the most efficient ac/dc-converter/PFC circuits. It’s important to understand the general categories for control and which power-supply types these methods can work with. A brief overview of active-PFC methods follows. For more information and circuit diagrams, see references 1 and 2.

The main control methods for active-PFC circuits are DCM (discontinuous-conduction mode), CCM (continuous-conduction mode), and CRM (critical-conduction mode). Various chip manufacturers have their own versions of CRM control, such as BCM (boundary-conduction mode) and TM (transition mode). “Current conduction” in these terms refers to the inductor current.

Low-power supplies typically use DCM. CCM works for all power levels but involves a hard reverse recovery of the output diode when the MOSFET switch turns on. This recovery can

cause high losses in a standard inexpensive diode. For high efficiency, therefore, you must use a more expensive diode, such as one made from silicon carbide.

In contrast, BCM circuits switch on the MOSFET with no current in the diode, allowing you to use inexpensive output silicon rectifiers. The trade-offs are that BCM uses a more complex variable-switching-frequency scheme, and its higher peak currents result in higher losses at higher power, limiting most BCM designs to less than 300W. At higher power levels, the CCM boost is more effective due to its lower ripple currents that result in lower peak currents and lower differential-mode EMI (electromagnetic interference).

However, recent innovations in converter/PFC design interleave multiple-

UTILITIES AND PFC

According to Ken Lau, consulting engineer for PG&E (Pacific Gas and Electric), a California electric utility, the utilities perform PFC (power-factor correction) by switching in banks of capacitors at preset times. In a residential area, you can expect a surge in power use at about 7 a.m., so the substation automatically switches in a capacitor bank at that time, switching it out after 8 a.m. No communication or real-time adjustment is necessary for this type of correction. In five to 10 years, however, many houses will have their own photovoltaic installations or perhaps even wind turbines, so the smart grid will be able to communicate with each house's power-subsystem inverter to perform PFC on the fly.

phase BCM-controller ICs, such as those from Fairchild, On Semiconductor, and Texas Instruments. Interleaved designs parallel two or more BCM power stages, allowing your design to reach 1 kW or more and reducing the ripple current in the output, which allows for smaller inductors. "If you look at the

costs of the controller in comparison to the costs of the PFC, which includes the inductor and all the power components, the controller is not a significant cost," says Jim Aliberti, product-marketing engineer at Texas Instruments. "It's the magnetics. People are looking for a way to reduce the costs, and inter-

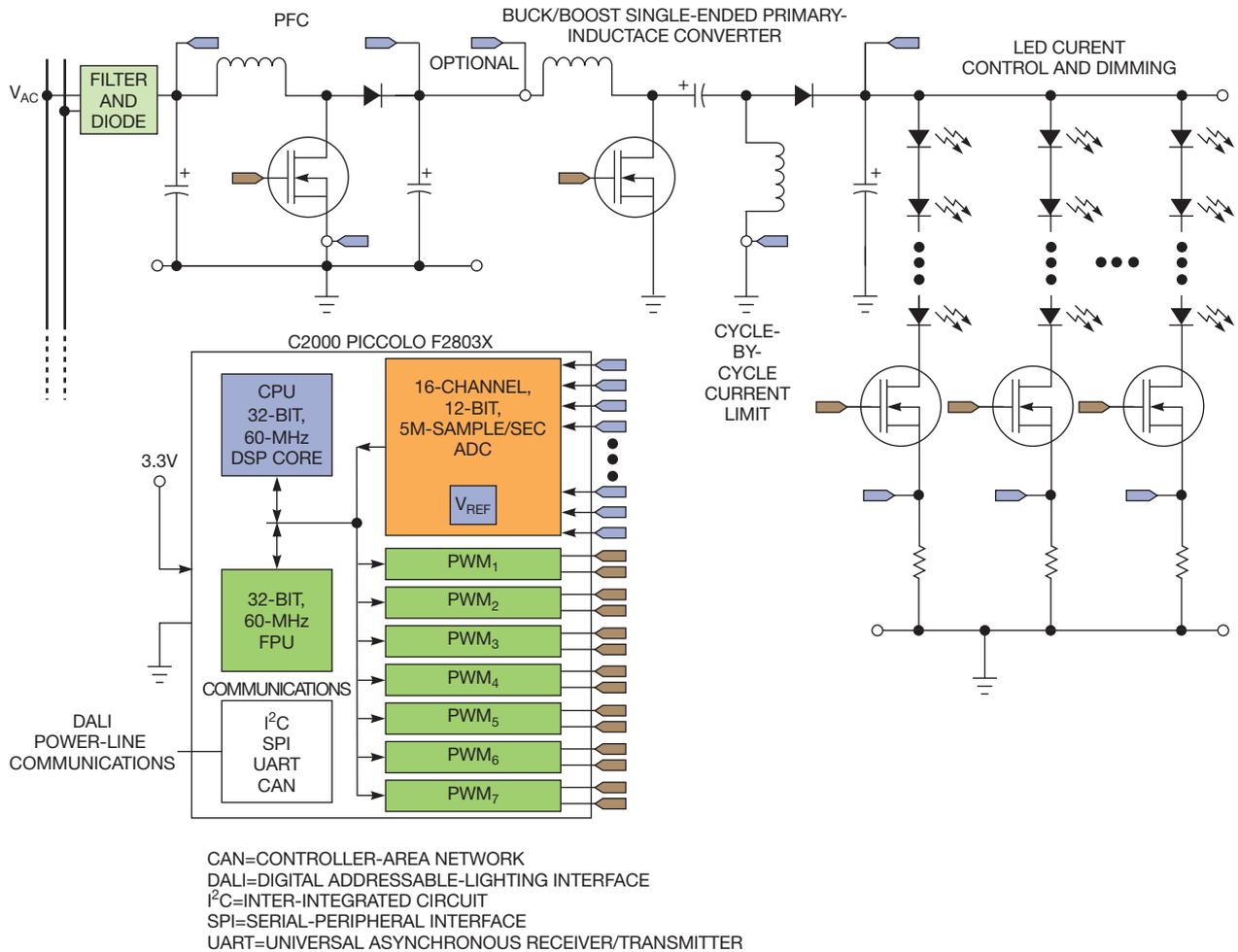
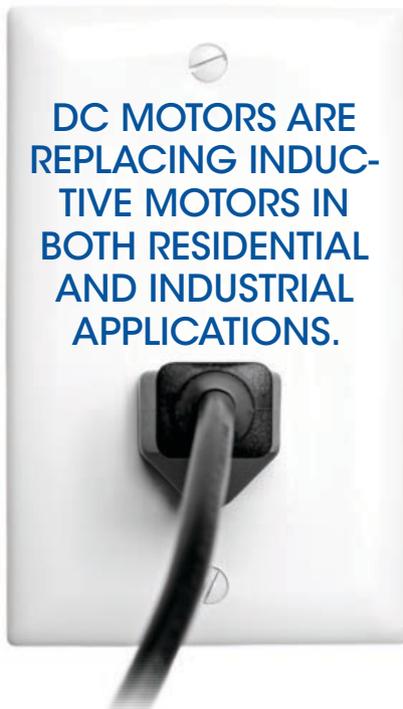


Figure 3 A microcontroller performs PFC by controlling the current so that it is sinusoidal and in-phase with the input voltage. The TI C2000 uses one control loop at 100 kHz to keep this input current sinusoidal and uses a second, slower control loop to keep the output voltage stable. The C2000 has sufficient CPU bandwidth to perform this task and multiple others for the system.

leaved design has enabled lower system costs because you don't have to process as much ripple current, allowing you to use smaller magnetics."

As with most power-conversion applications, digital power is making inroads into PFC, as well. For example, Cirrus Logic offers an IC for digitally controlled PFC. The active-PFC CS1500 and CS1600 DCM ICs target use in power supplies requiring as much as 300W. The CS1500 addresses power supplies for applications such as laptops, digital TVs, and PCs, and the CS1600 targets electronic-lighting ballasts. At approximately 30 cents (high volumes), the chips compare in price with analog PFC ICs but use 30% fewer additional components and fewer parts for EMI filtering. The power factor, which varies with the input line voltage and the load, is greater than 0.95. The iW3620 LED driver from iWatt is also a digital single-stage, active-PFC device. Texas Instruments offers a development kit for high-voltage PFC, which includes hardware and software to implement two-phase interleaved digital PFC for regulation compliance. The kit can work with the company's application-development kits for the C2000 Piccolo microcontrollers, such as the C2000 ac/dc developer's kit, as well as end-product kits, such as motor-control and LED-lighting-control kits.

Providing efficiency of as much as 30% in applications such as air conditioners and refrigerators, dc motors are replacing inductive motors in both residential and industrial applications. Because of their complex control algorithms, most dc-motor controllers use a DSP. Designers can add digital PFC to designs that already have a DSP—often with no additional components. The cost in engineering learning time



can be considerable, though, which is why TI offers its DSP-developer kits for several applications. The digital-PFC kit can work to provide a PFC block for a DSP-motor controller. Another likely application for digital PFC is LED lighting. For example, a DSP such as the C2000 can run PFC in addition to powering an LED array (**Figure 3**).

Do you remember the advertising push several years ago for the smart refrigerator that would track when you were low on milk and autonomously order more? That idea didn't catch on. Perhaps the more likely intelligence will be a DSP that controls all of the power-efficient function of home appliances. **EDN**

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