Rectifiers for Power Factor Correction (PFC)

CCM (Continuous-Conduction-Mode) and CRM (Critical-Conduction-Mode) devices are most widely adapted in commercial applications for power factor correction. CCM devices are often used in SMPS with output power ratings greater than 300 W; while CRM devices are often used in SMPS with output power ratings less than 300 W. CRM PFC devices operate in the boundary mode between CCM PFC and DCM (Discontinuous-Conduction-Mode) PFC devices.

PFC devices are generally selected base on the speed of their reverse recovery time (t_{rr}). Currently for CCM and CRM PFC devices in market, rectifiers up to 600 V with t_{rr} smaller or equal to 35 ns are generally used as CCM PFC; rectifiers up to 600 V with reverse recovery time between 35 ns to 60 ns are used as CRM PFC.

It should be noted there is a tradeoff between forward voltage drops and switching speed; when the reverse recovery time of Ultrafast rectifiers are less than 35 ns, their forward voltage drops would increase significantly, in turn the devices' forward surge current abilities would be diminished, therefore cautious attention should be taken when selecting the appropriate CCM or CRM PFC devices for various switch mode power supply applications, such that expected performance could be achieved and better reliability would still be ensured.

WHAT ARE THE EFFECTS OF NON-PFC-EQUIPPED CIRCUITS

Non-PFC power supplies use a capacitive input filter, as shown in Figure 1, when powered from AC power line. This results in rectification of the AC line, which in turn causes peak currents at the crest of the AC voltage, as shown in Figure 2. These peak currents lead to excessive voltage drops in the wiring and imbalance problems in the three-phase power delivery system. This means that the full energy potential of the AC line is not utilized.

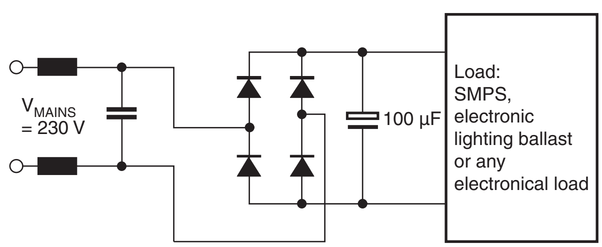

Figure 1. Standard Bridge Rectification of Line Voltage

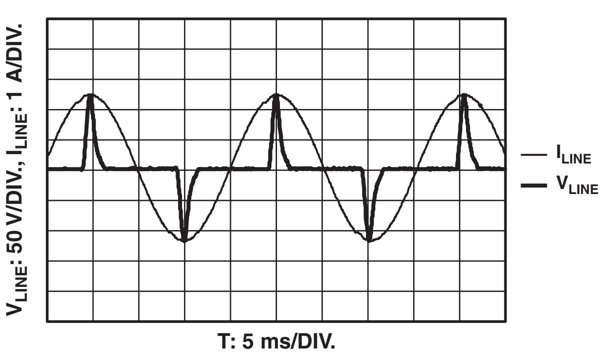

Figure 2. 20 W Resistive Load Powered by a Circuit Like Fig. 1

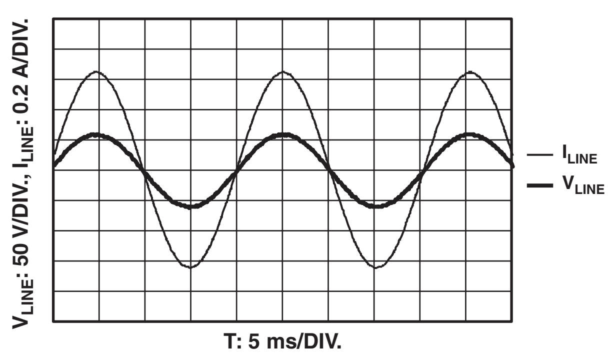

Figure 3. Same Load Like Fig. 2, but Unity Powerfactor

Power Factor Correction (PFC) can be defined as the reduction of the harmonic content. By making the current waveform look as sinusoidal as possible, as shown in Figure 3, the power drawn by the power supply from the line is then maximized to real power. Assuming that the voltage is almost sinusoidal, power factor depends first of all on the current waveform.

Thus real power can be defined as:

$$P = V_{RMS} \times I_1 \times \sin(\omega_1 t)$$

$$S = \sqrt{P^2 + Q^2}$$

$$S = V_{RMS} \times \sqrt{I_1^2 \times \sin(\omega_1 t)^2 + I_2^2 \times \sin(\omega_2 t)^2 + ... + I_n^2 \times \sin(\omega_n t)^2}$$

That means that real power only is carried by the fundamental harmonic, all the higher harmonics are carrying only reactive power. Eliminating the higher harmonics means increasing power factor to unity.

The defination of power factor is:

$$\text{Power factor} = \frac{\text{Real power}}{\text{Apparent power}}$$

For the circuit in Figure 1 the power factor is typically about 40 to 50 %.

For example (related to figures 1 and 2):

The following measurements can be done with the circuit in Figure 1:

C =	100 µF	R =	680 Ω
I_{TRMS} =	495 mA	P =	20 W
S =	43 VA	Q =	38 var
Power factor =	0.464		

With the same resistor directly connected to the line terminals or using power factor correction the following results can be achieved:

I_{TRMS} =	172 mA	P =	20 W
S =	20 W	Q =	0
Power factor =	1		

This simple example gives a good impression what happens if all electronic equipment is powered without PFC. Obviously we see in this example the same real power, but big differences in RMS current.

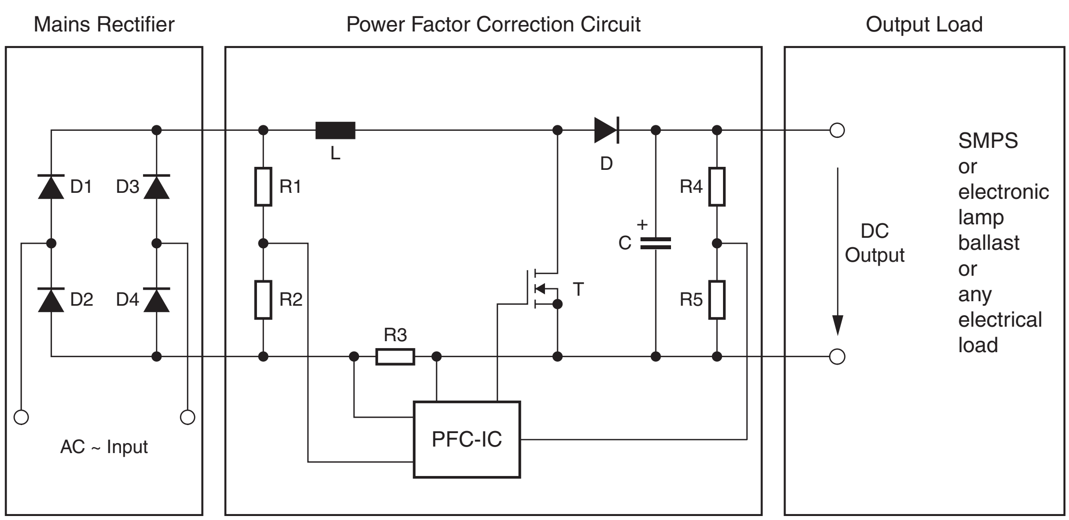

Figure 4. Typical Boost Converter Topology for Active PFC

Because it is the most cost saving solution the continuous conduction mode (CCM) boost converter as shown in figure 4 is today the most used topology for active power factor correction.

The bridge rectifier BR1 converts the AC input current into DC current. The MOSFET T is used as an electronic switch, and is cycled “on” and “off” driven by the PFC-IC. While the MOSFET is “on” the inductor current through L increases. While the MOSFET is “off”, the inductor delivers current to the capacitor C through the forward biased output rectifier diode D. The inductor current does not fall to zero during the entire switching cycle, because this operation is called “continuous conduction mode (CCM)”. This mode is suitable for almost all load current variations. If a constant load current is expected the so-called “discontinuous conduction mode (DCM)”, where currents falls at the end of each cycle to zero, should be preferred. The MOSFET anyway is pulse-width-modulated so that the input impedance of the circuit appears purely resistive, and the ratio of peak to average current is kept low.

The most cost-effective way of reducing losses in the circuit is by choosing a suitable diode D for the application. Diodes for use in PFC circuits typically have higher forward voltages than conventional fast epitaxial diodes, but much shorter (faster) reverse recovery times.

HOW A STANDARD PFC CIRCUIT WORKS

Figure 4 shows the typical topology of a PFC pre-stage that is built of a standard boost converter driven by a control IC. It is important that at the output of the Rectifier BR1 there will be no "large" smoothing capacitor with several µF connected, because that would eliminate all efforts of the PFC circuit, although it would operate sufficiently. The input voltage of the PFC is a rectified DC voltage pulsed with double line frequency. The shown switch is usually implemented by an IGBT or Power-MOS transistor.

Operation principle:

The instantaneous value of the current through the boost inductor has to be adapted as well as possible to the instantaneous value of the line voltage through suitable pulse-width modulation of the transistor switch T. The actual inductor current can be won by the voltage drop at R3. The input voltage can be found at the voltage divider R1, R2. The current amplitude will be regulated on the value of the output voltage, R4, R5.

To be able to control the current through the boost inductor, the output voltage of the PFC has to be higher at every moment of operation than the crest of the line input voltage. For 230 V mains the DC output should be about 400 V. A large capacitor at the ouput does not affect the power factor, but is good for smoothing the DC voltage.

An additional advantage of PFC circuit is the regulated DC voltage that gives the opportunity of having a following SMPS to be wide range operated (e.g. 110 V to 230 V input voltage).

ADVANTAGES OF CIRCUITS WITH PFC

- The use of PFC allows the manufacturer of electrical load to use smaller, more cost-effective mains rectifiers because of smaller RMS current with PFC.
- Offers a stable regulated output voltage which is the input voltage for the following electrical load. Indeed the PFC makes it a system based wide-range power supply itself.
- The following electrical load (SMPS, Electronic ballast unit or other electrical load) can be much simpler, which is also a cost saving factor.

VISHAY General Semiconductor recommends the use of their ultrafast rectifier series of PFC rectifier.

RECOMMENDED REVERSE VOLTAGES FOR MOST USED LINE VOLTAGE LEVELS

V_{LINE} RMS (V)	V_{RRM} (V)
110	400
120	400
230	600
277	600