ACTIVE POWER LINE FILTERS FOR SWITCHING POWER SUPPLIES

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Abstract. This paper analyses two schemes of single-stage diode-switched active filters used in new switching power supplies designs to improve the power factor. From the point of view of the power flow, the distortion reduction is based on the improvement of the power conversion processes. Most of the ca/cc switching power supplies consists of two separated parts: a rectifier – in most cases a diode bridge, and the converter itself. In the diode rectifiers with capacitive smoothing of the output voltage, considerable harmonic reduction can be achieved by converting the second-harmonic power in single-phase rectifiers and the third-harmonic power in three-phase rectifiers into an additional quantity of dc power. This promising trend is implemented using the diode-switched-inductor and the diode-switched-transformer filter stages. A second harmonic or third harmonic series resonant filter can ensure a quasi-sinusoidal operation mode with a power factor up to 0.995.

Keywords: power factor correction, power converter, diode rectifier, diode switched active filter

Introduction

Switching mode power supplies and power converters are widely used in many industrial and domestic applications. This results in creation of high frequency emissions by the commutation of the power semiconductor switches. These are controlled at regular intervals and are at the origin of the conducted and radiated emissions. Chopping operations can generate currents with various waveforms. The resulting spectra have different magnitudes of high frequency harmonic components. Other sources of EMI noise are the diode-bridge rectifiers, present in almost all switching power supplies. From the point of view of the power flow, rectification is based on the consumption of the supply harmonic power and generation of dc power. This is possible only in the operation mode with the alternation of the conducting and non-conducting states of the rectifier switches. With such inevitable harmonic sources, the only task remains to
reduce the magnitude of the unwanted harmonics to a minimum, to localize them within the conversion circuit, and thus to reduce the input and output distortions to an acceptable level. Active filters using fully controlled switches may provide considerable harmonic reduction and power factor improvement by means of second harmonic power conversion into an additional quantity of dc power (in single phase rectifiers). The single-stage active filter provides 0.97 ... 0.98 power factor for the single-phase rectifiers and 0.99 power factor for the three-phase rectifiers.

In this paper, we analyze two types of single-stage active filters and present some practical results both from computer simulation and from measurements.

**Principles and modes of operation**

Let us consider the block diagram of a switching power supply in Figure 1:

![Block diagram of a switching power supply](image)

**FIGURE 1.** Block diagram of a switching power supply

The circuit contains a diode bridge rectifier, a smoothing capacitor \( C \) and a current-shaping active filter \( AF \), modeled by a current source \( I_d \) and two voltage sources: \( v_d \) and \( U_0 \). Figure 3 shows that the function of the active filter is to convert the second-harmonic power \( P_{d2} \) into additional quantity of dc power \( P_{AF0} = I_{d0} \cdot U_0 \) where \( I_{d0} \) denotes the dc component of the rectified current \( I_d \). In Figure 3, for the ideal case, the average supply power \( P_S \), rectified
power $P_d$ and the output power $P_0$ are equal. The symbol $P_{d0}$ denotes the dc component of the rectified power.

Let us determine the part of the second harmonic power $P_{d2}$ in the total rectified power $P_d$. Assume that the rectifier is ideal and the output capacitance $C$ equals infinity, the supply voltage is:

\[ v_s = \sqrt{2}V_s \sin \omega t = V_m \sin \omega t \]

\[ v_d = \left| v_s \right| = \sqrt{2}V_s \left| \sin \omega t \right| = \frac{2\sqrt{2}}{\pi}V_s \left( 1 - \frac{2}{3} \cos 2\omega t - \frac{2}{15} \cos 4\omega t - \frac{2}{35} \cos 6\omega t - \ldots \right) \quad (1) \]

\[ v_d = V_{d0} + v_{d2} + v_{d4} + v_{d6} + \ldots = V_{d0} + v_{d2} \]

In the ideal sinusoidal current mode operation with $i_s = \sqrt{2}I_s \sin \omega t = I_m \sin \omega t$, the rectified current is:

\[ i_d = \left| i_s \right| = \sqrt{2}I_s \left| \sin \omega t \right| \]

\[ i_d = \frac{2\sqrt{2}}{\pi}I_s \left( 1 - \frac{2}{3} \cos 2\omega t - \frac{2}{15} \cos 4\omega t - \frac{2}{35} \cos 6\omega t - \ldots \right) = I_{d0} + i_{d2} + i_{d4} + \ldots = I_{d0} + i_d \]

\[ P_{d0} = 8V_sI_s \left( \frac{8}{\pi^2} \right) P_d = 0.8106P_d \quad (3) \]

\[ P_{d2} = \left( \frac{4}{3\pi} \right)^2 P_d = 0.1801P_d \quad ; \quad P_{d4} = 0.0072P_d \quad (4) \]

According to (3) and (4) in the ideal sinusoidal operation mode, the dc and the second harmonic average powers constitute 81 and 18 per cent of the total rectified power $P_d$ and $P_{d0} + P_{d2} = 0.9907P_d$.

To implement the sinusoidal operation mode, AFs using fully controlled switches have to be used. A simpler quasi-sinusoidal operation mode, which provides an approximately sinusoidal supply current, has been proposed in [6]. It is characterized by the rectified current:

\[ i_d = I_{d0} + i_{d2} = I_0 \left( 1 - \frac{2}{3} \cos 2\omega t \right) \quad (5) \]
Taking into account the harmonic content of the rectified voltage (1) and rectified current (5), the dc component and the second harmonic average power of the rectified power are:

\[ P_{d0} = I_{d0}.V_{d0} = \left( \frac{2\sqrt{2}}{\pi} \right) V_s I_0 \quad \text{and} \quad P_{d2} = I_{d2}.V_{d2} = \left( \frac{4\sqrt{2}}{9\pi} \right) V_s I_0 \]  

(6)

where \( I_{d2} \) and \( V_{d2} \) denotes the rms values of the second harmonic current and voltage. The total average rectified power is:

\[ P_d = P_{d0} + P_{d2} = \left( \frac{22\sqrt{2}}{9\pi} \right) V_s I_0 \]  

(7)

From (6) and (7) we obtain:

\[ P_{d0} = \left( \frac{9}{11} \right) P_d = 0.8182 P_d \quad \text{and} \quad P_{d2} = P_{AF0} = \left( \frac{2}{11} \right) P_d = 0.1818 P_d \]  

(8)

Consequently, in the ideal quasi-sinusoidal mode we have:

\[ P_0 = P_d = \left( 1 + \frac{2}{9} \right) P_{d0} = 1.222 P_{d0} \quad (9) \]

\[ V_0 = V_d + U_0 = \left( 1 + \frac{2}{9} \right) V_{d0} = 1.222 V_{d0} > V_{d0} \]  

(10)

The supply current \( i_s = i_d . \text{sign}(\sin \omega t) = \sqrt{2} I_{s1} \cdot \sin \omega t - \sqrt{2} I_{s3} \cdot \sin 3\omega t + ... \) where:

\[ I_{s1} = 22\sqrt{2} I_0 \cdot \frac{1}{9\pi} \quad \text{and} \quad I_{s3} = 2\sqrt{2} I_0 \cdot \frac{1}{15\pi} \]  

are the rms values of the fundamental and the third supply current harmonics.

From (5) the rms values of the rectified current \( I_d \) and supply current \( I_s \) can be written:

\[ I_d = I_s = I_0 \cdot \sqrt{1 + \frac{2}{9}} = I_0 \sqrt{\frac{11}{9}} \]  

(11)

From (11) the input power factor is:

\[ PF = \frac{V_s I_{s1}}{V_s I_s} = \frac{I_{s1}}{I_s} = \frac{22\sqrt{2}}{3\pi \sqrt{11}} = 0.9953 \]  

(12)

which is very close to unity.

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**FIGURE 4.** Single-phase diode rectifier with a current shaping active filter
Figure 4 presents a first topology of an active filter. We simulated this filter, some practical results are presented below ($L_1=L_2=L_3=L_f$; $C_f=500\mu F$).

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<th>k</th>
<th>$L_f$ (mH)</th>
<th>$i_{2n}$ (A)</th>
<th>$i_{LOAD}$ (A)</th>
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<td>200</td>
<td>300</td>
<td>400</td>
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<td>1.87</td>
<td>0.27</td>
<td>0.32</td>
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<td>1.87</td>
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TABLE 1. Amplitude of the even-order harmonics of the filter presented in Figure 4

Better practical results may be obtained with a more expensive filter, presented in Figure 5.

![FIGURE 5. Single-phase diode rectifier with a current shaping active filter](image)

The most difficult component to be built is the filter transformer because the saturation current of the magnetic core must be high enough to prevent saturation on the working current value.

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<tr>
<th>k</th>
<th>N1:N2</th>
<th>$L_f$</th>
<th>$C_{CB}$</th>
<th>$C_f$</th>
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TABLE 2. Amplitude of the even-order harmonics of the filter presented in Figure 5
The simulation results are presented in Table 2 and Figure 6. On observe better harmonics reduction both on high and low order current harmonics in the load and in the input current comparing to the filter in Figure 4.

**Conclusions**

Harmonic reduction is the only way to reduce the total harmonic distortion of the output current of the rectifiers present in almost all switching power supplies. Increasing the power factor must be one of the first aims of a power utility interface designer. The two schemes of active filters presented are cost-effective solutions for reducing the utility harmonic pollution.

**References**


