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 al 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:

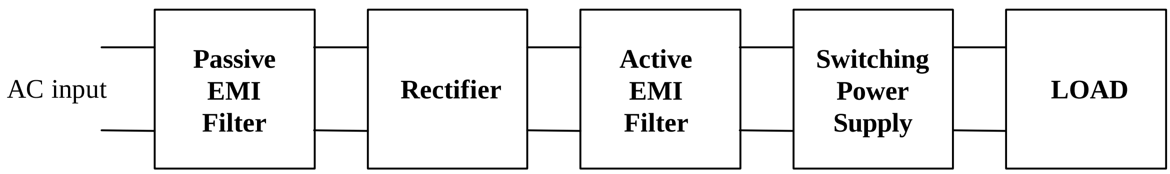

FIGURE 1. Block diagram of a switching power supply

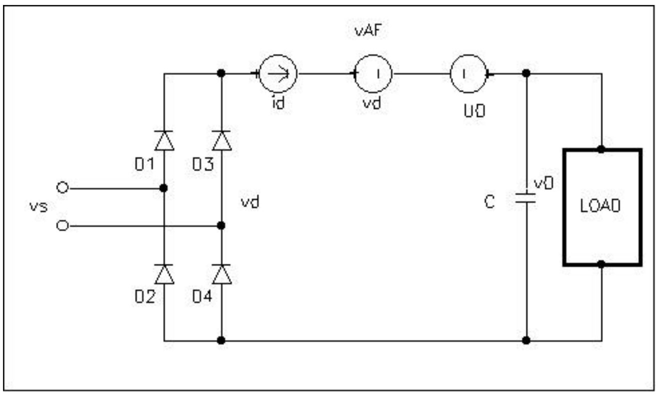

FIGURE 2. Equivalent of a single-phase diode rectifier
with current-shaping active filter AF

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 $P_{AF0} = I_{d0}.U_0$ 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.

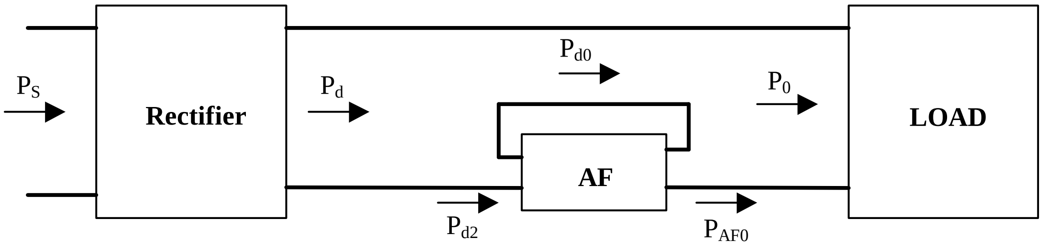

FIGURE 3. Power flow diagram for the circuit in Figure 2

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:

$$v_s = \sqrt{2}.V_S.\sin\omega t = V_m.\sin\omega t$$
$$v_d = |v_s| = \sqrt{2}.V_S.|\sin\omega t| = \frac{2\sqrt{2}}{\pi}.V_S.\left(1-\frac{2}{3}.\cos 2\omega t-\frac{2}{15}.\cos 4\omega t-\frac{2}{35}.\cos 6\omega t-...\right) \quad (1)$$
$$v_d = V_{d0}+v_{d2}+v_{d4}+v_{d6}+... = V_{d0}+v_{d\approx}$$

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:

$$i_d = |i_S| = \sqrt{2}.I_S.|\sin\omega t| \quad (2)$$
$$i_d = \frac{2\sqrt{2}}{\pi}.I_S.\left(1-\frac{2}{3}.\cos 2\omega t-\frac{2}{15}.\cos 4\omega t-\frac{2}{35}.\cos 6\omega t-\right) = I_{d0}+i_{d2}+i_{d4}+... = I_{d0}+i_d$$
$$P_{d0} = 8.V_S.I_S.\frac{1}{\pi^2} = \left(\frac{8}{\pi^2}\right)P_d = 0.8106.P_d \quad (3)$$
$$P_{d2} = \left(\frac{4}{3\pi}\right)^2.P_d = 0.1801.P_d;\quad P_{d4} = 0.0072.P_d \quad (4)$$

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 $P_{d0}+P_{d2} = 0.9907.P_d$.

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:

$$P_{d0} = I_{d0}.V_{d0} = \left(\frac{2\sqrt{2}}{\pi}\right)V_S.I_0 \text{ and } P_{d2} = I_{d2}.V_{d2} = \left(\frac{4\sqrt{2}}{9\pi}\right)V_S.I_0 \tag{6}$$

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

$$P_d = P_{d0} + P_{d2} = \left(\frac{22\sqrt{2}}{9\pi}\right)V_S.I_0 \tag{7}$$

From (6) and (7) we obtain:

$$P_{d0} = \left(\frac{9}{11}\right)P_d = 0.8182.P_d \text{ and } P_{d2} = P_{AF0} = \left(\frac{2}{11}\right)P_d = 0.1818.P_d \tag{8}$$

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

$$P_0 = P_d = \left(1 + \frac{2}{9}\right)P_{d0} = 1.222.P_{d0} > P_{d0} \tag{9}$$

$$V_0 = V_d + U_0 = \left(1 + \frac{2}{9}\right)V_{d0} = 1.222.V_{d0} > V_{d0} \tag{10}$$

The supply current $i_S = i_d.\text{sign}(\sin\omega t) = \sqrt{2}.I_{S1}.\sin\omega t - \sqrt{2}.I_{S3}.\sin 3\omega t + \ldots$ where: $I_{S1} = 22\sqrt{2}.I_0.\frac{1}{9\pi}$ and $I_{S3} = 2\sqrt{2}.I_0.\frac{1}{15\pi}$ 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:

$$I_d = I_S = I_0.\sqrt{1 + 2/9} = I_0.\sqrt{\frac{11}{9}} \tag{11}$$

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.

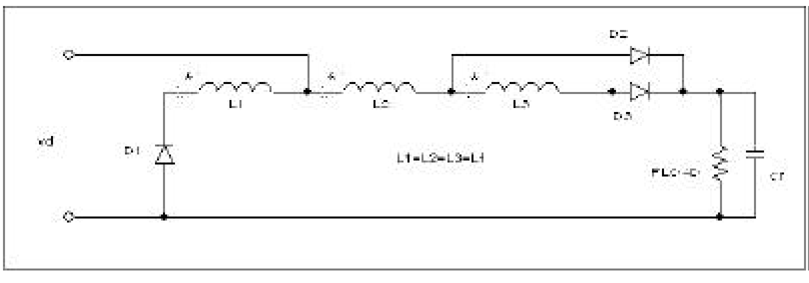

FIGURE 4. Single-phase diode rectifier with a current shaping active filter

Figure 4 presents a first topology of an active filter. We simulated this filter, some practical results are presented below ($L_1=L_2=L_3=L_f$; $C_f=500\mu F$).

		i_{2n} (A)				i_{LOAD} (A)				
k	**L_f**	**100**	**200**	**300**	**400**	**100**	**200**	**300**	**400**	
0.9	1 mH	3.80	1.77	0.39	0.09	3.75	1.71	0.35	0.05	with filter
0.9	10 mH	2.93	1.53	0.68	0.29	2.10	0.82	0.20	0.03	
0.9	100 mH	2.34	1.42	0.66	0.24	1.45	0.75	0.26	0.07	
-	-	5.58	1.87	0.27	0.32	5.58	1.87	0.27	0.32	without filter

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.

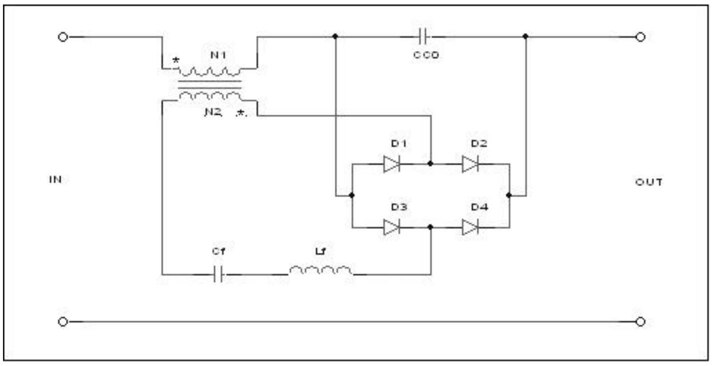

FIGURE 5. Single-phase diode rectifier with a current shaping active filter

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.

					i_{2n}(A)				i_{LOAD}				
k	**N1:N2**	**L_f**	**C_{C0}**	**C_f**	**100**	**200**	**300**	**400**	**100**	**200**	**300**	**400**	
0.9	1:3	10m	10u	10u	2.83	1.58	0.49	0.06	2.70	1.34	0.36	0.04	with filter
0.9	1:5	10m	10u	10u	2.81	1.53	0.46	0.06	2.68	1.29	0.34	0.04	
0.9	1:10	10m	10u	10u	2.70	1.31	0.37	0.05	2.58	1.11	0.27	0.03	
0.9	1:30	10m	10u	10u	1.88	0.65	0.16	0.01	1.79	0.55	0.11	0.01	
					5.58	1.87	0.27	0.32	5.58	1.87	0.27	0.32	without filter

TABLE 2. Amplitude of the even-order harmonics of the filter presented in Figure 5

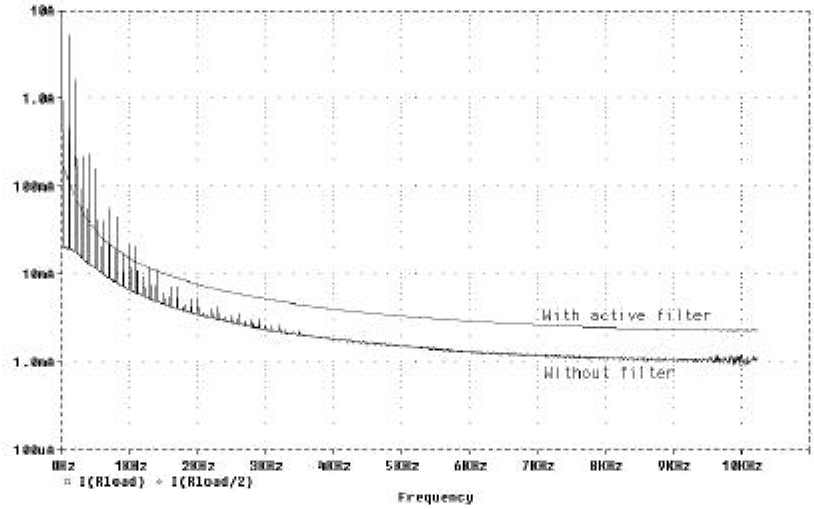

FIGURE 6. The spectrum of the output current with/without using the active filter

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.

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