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Single-Phase Active Power Filter for Harmonic Sources

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ABSTRACT: There are two types of harmonic sources in power system, i.e., voltage-type harmonic source and current-type harmonic source, in this paper the physical essential of the two types of harmonic sources is firstly analyzed by simulation. And then a novel series active power filter is proposed when the load is voltage type harmonic source. The novel series active power filter is from the active power filter with fundamental magnetic flux compensation (FMFC). The difference between the proposed active power filter and the active power filter with FMFC is that the proposed active filter is without passive filter and the proposed active filter is only suitable for the filtering of the voltage type harmonic source. Therefore the novel series active power filter is with smaller bulk and lower cost. The main circuit and filtering principle are analyzed in detail in the paper. The simulation model is established while the load is voltage-type harmonic source. The simulation results verify the principle analysis.

KEYWORDS: Active power filter (APF), Harmonic Sources, transformer.

I.INTRODUCTION

Harmonic interference problems in power system become increasingly serious due to the wide application of power electronic equipments and nonlinear loads in recent years and harmonic contamination affects the power utility in many aspects. Many shunt passive filters and active power filters have been proposed and developed [1-5]. However, passive filters may cause resonance phenomenon and the source impedance strongly affects the filtering characteristics. Active power filters have attracted more attention. So far, there are two types of typical active filters in terms of their configurations [3-7], conventional shunt active filter and series active power filters. Harmonic sources can be classified into two types: current- type harmonic source and voltage-type harmonic source. In general, the shunt active power filter is suitable for filtering harmonic currents of the current-type harmonic source and series active power filter is suitable for compensating voltage of voltage-type harmonic sources. Among these configurations, a series hybrid active power filter with fundamental magnetic flux compensation (FMFC) of the series transformer is proposed in [6]. Only the fundamental current is detected and tracked in the active power filter with FMFC, and the bandwidth requirement of the filtering system is much lower and the control scheme is easier to be realized as compared with the other active power filters. And the filter with FMFC is suitable for two types of typical harmonic-producing loads and the filtering characteristic is independent with the type of harmonic sources. The filter is a combined of active and passive power filter. A novel active power filter is proposed when it is only used for filtering of voltage-type harmonic sources. The difference between the proposed active power filter and the active power filter with FMFC is that the proposed active filter is without passive power filter and with smaller bulk and lower cost [8-10].

The organization of this paper is as follows, The physical essential of the two types of harmonic sources is firstly analyzed and explained by simulation results. Secondly, the main circuit and principle of the novel series active power filter are analyzed in detail. Thirdly, the simulation model of the active filtering system is established while the load is voltage-type harmonic source and the filtering simulation results are given.

II. HARMONIC SOURCES

Fig. 1(a) shows the simulation model of the current-source type harmonic source as there is a large inductance in series connecting with the load, which will produce the constant DC current. The system current waveform is shown as in Fig. 1(b). Because the harmonic current contents and characteristics are less dependent upon the ac side, this type of harmonic source behaves like a current source. Therefore, this harmonic source is current-type harmonic source. Fig. 2(a) shows the simulation model of the voltage-source type harmonic source as there is large capacitors in parallel connecting with the load, which will produce the constant DC voltage. The system current waveform is shown as in

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Fig. 2(b). Because the harmonic voltage contents and characteristics are less dependent upon the ac side, this type of harmonic source behaves like a voltage source. Therefore, this harmonic source is voltage-type harmonic source.

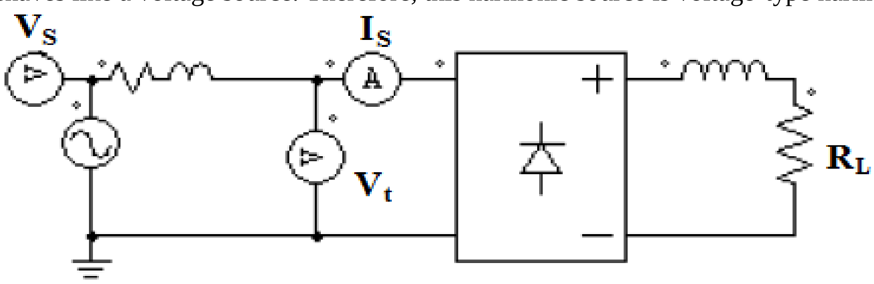

Fig. 1 (a): Simulation model of the current-source type harmonic source

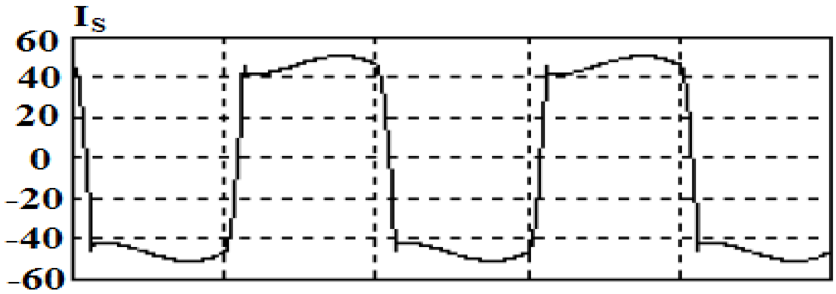

Fig. 1(b): System current simulation waveform of Fig.1 (a)

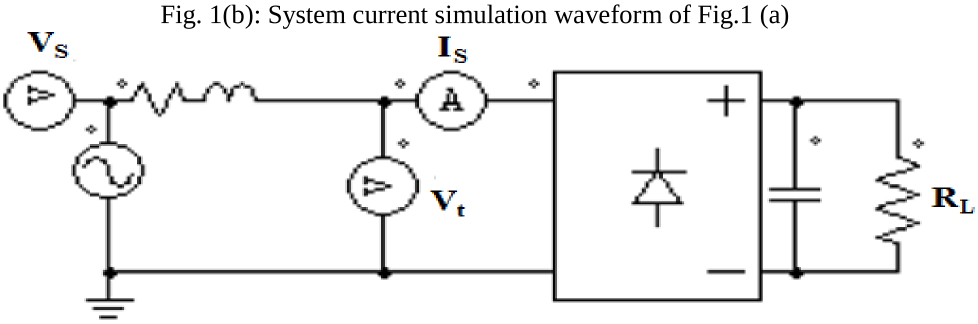

Fig. 2(a): Simulation model of the voltage-source type harmonic source

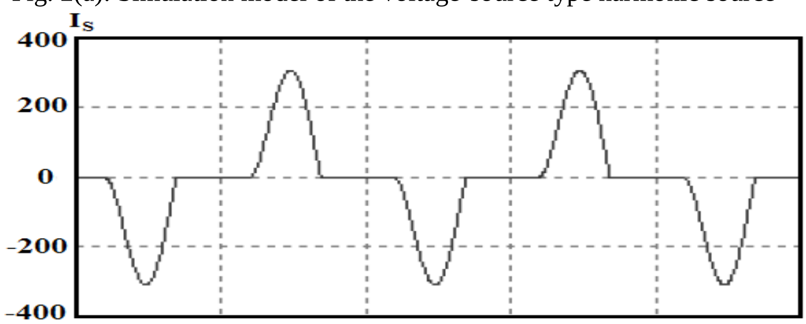

Fig. 2(b): System current simulation waveform of Fig.2 (a)

In general, the shunt passive and active power filter is effective for filtering the current harmonic of the current-source type harmonic source; the series passive and active power filter is effective for compensating the voltage harmonic of the voltage-source type harmonic source.

III. MAIN CIRCUIT AND PRINCIPLE ANALYSIS

Fig.3 shows the detailed system configuration of the novel series hybrid single-phase active power filter suitable for the voltage-source type harmonic source. It is almost the same as the system configuration of the active power filter with

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FMFC expect that the novel series active power filter is without the passive power filter. There is a series transformer in the novel active power filter, the series transformer is with air gap, and its circuit and T-type equivalent circuit is shown as in Fig.4 and Fig.5, respectively. The turns of primary and secondary winding of the transformer are W_1 and W_2, respectively; the turns ratio is represented by $k = W_1 / W_2$. Assume that the primary winding AX is inserted in series between the power utility and a harmonic-producing load. Then the source current, i.e. the primary current, consists of the fundamental current and n^{th} order harmonic currents, that is to say, $i_1^{(1)} = i_1^{(1)} + \sum i_1^{(n)}$. The fundamental component $i_1^{(1)}$ is detected from the power utility current i_1 and followed by applying a voltage source inverter so as to produce a fundamental current $i_2^{(1)}$, which has the same frequency as $i_1^{(1)}$ and $i_2^{(1)}$ is inversely in phase injected to the secondary winding ax.

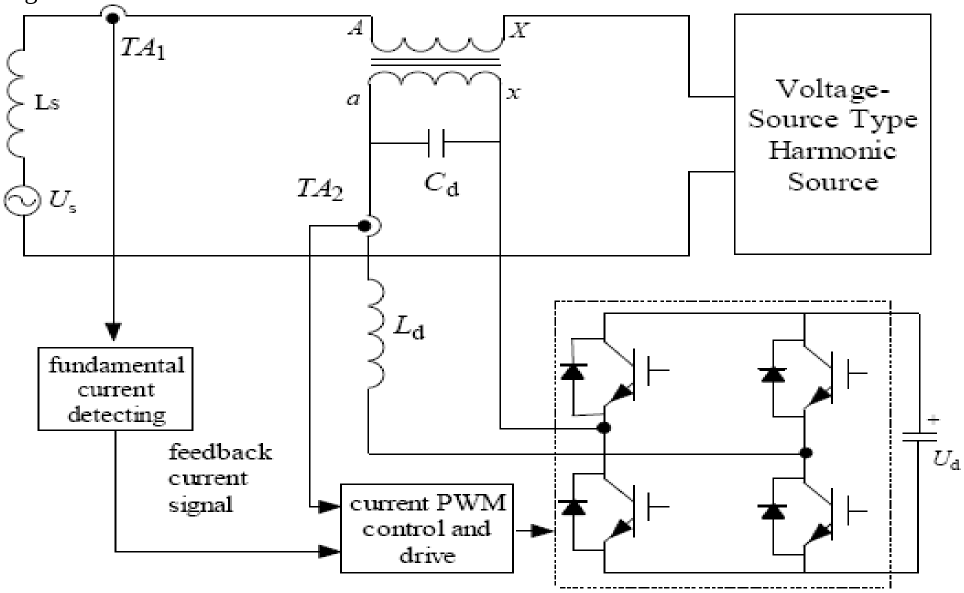

Fig. 3: Novel series active power filter Configuration

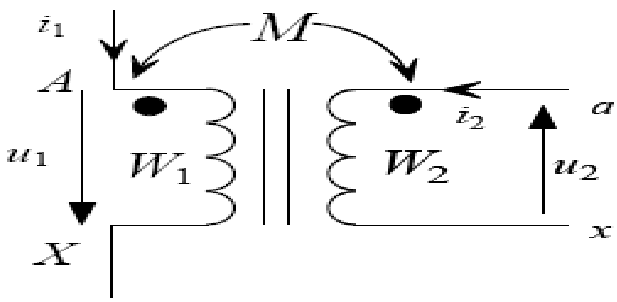

Fig. 4: Series transformer circuit

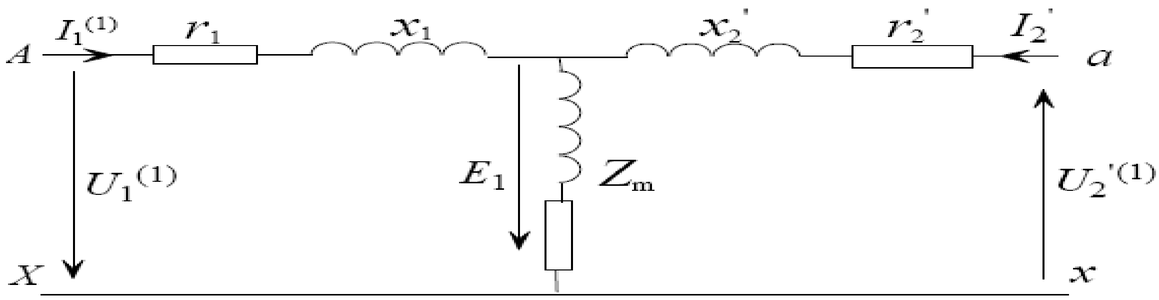

Fig. 5: The T- type equivalent circuit

From the equivalent T circuit, we can obtain the voltage equivalent in phasor form.

$$\begin{cases} \bar{U}_1 = \dot{I}_1 Z_1 + (\dot{I}_1 + \dot{I}'_2)\, Z_m & (1) \\ -\bar{U}'_2 = \dot{I}'_2 Z'_2 + (\dot{I}_1 + \dot{I}'_2)\, Z_m & (2) \end{cases}$$

Where $Z_1 = r_1 + jx_1$ is the leakage impedance of primary winding; $Z'_2 = r'_2 + jx'_2$ is the leakage impedance of secondary winding referred to primary winding; $Z_m = r_m + j\,x_m$ is the magnetizing impedance of the transformer. For the fundamental, when the injected fundamental current i_2 Satisfies $\dot{I}_1 + \dot{I}'_2 = 0$ i.e. $W_1\,\dot{I}_1 + W_2\,\dot{I}_2 = 0$, which is the fundamental magnetic flux compensation, then the following equations can be derived:

$$\begin{cases} Z_{AX} = \bar{U}_1 / \dot{I}_1 = Z_1 & (3) \\ Z_{ax} = -\bar{U}'_2 / \dot{I}'_2 = Z'_2 & (4) \end{cases}$$

The primary and secondary impedance equations (3) and (4) suggest the equivalent circuit of the series transformer to the fundamental shown in Fig.6. For nth order harmonic, since only a fundamental current is injected to the secondary winding of the transformer, i_2 doesn't include any order harmonic besides the fundamental current. In this case, according to the T-type equivalent circuit of the Fig.5

$$U_1 = (r_1 + jnx_1)\, I_1 + Jnx_m\, I_1 \qquad (5)$$

From the terminals AX, the equivalent impedance is

$$Z_{AX} = U_1 / I_1 = (r_1 + jnx_1) + Jnx_m \approx n\,Z_m \qquad (6)$$

According to equations (6), equivalent circuit of the transformer to nth order harmonic can be represented by Fig.7.

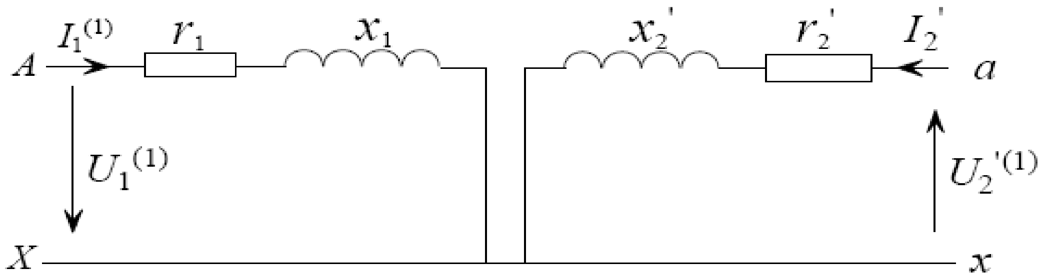

Fig. 6: Fundamental equivalent circuit

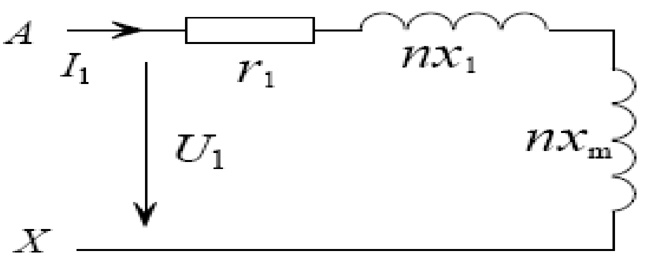

Fig. 7: Harmonic equivalent circuit

IV. SIMULATION RESULTS AND EXPERIMENT

To demonstrate the validity of the novel series active power filter for voltage-source type harmonic source, a PSIM simulation model was established in the term of the principle as shown in Fig. 8. Herein, the turns ratio of a series transformer is 1:1, the tested value of the short and magnetizing impedance of the series transformer are 0.11 Ω and 13.16Ω, respectively. The rms value of source voltage and current are 295V and 45.8A, respectively.

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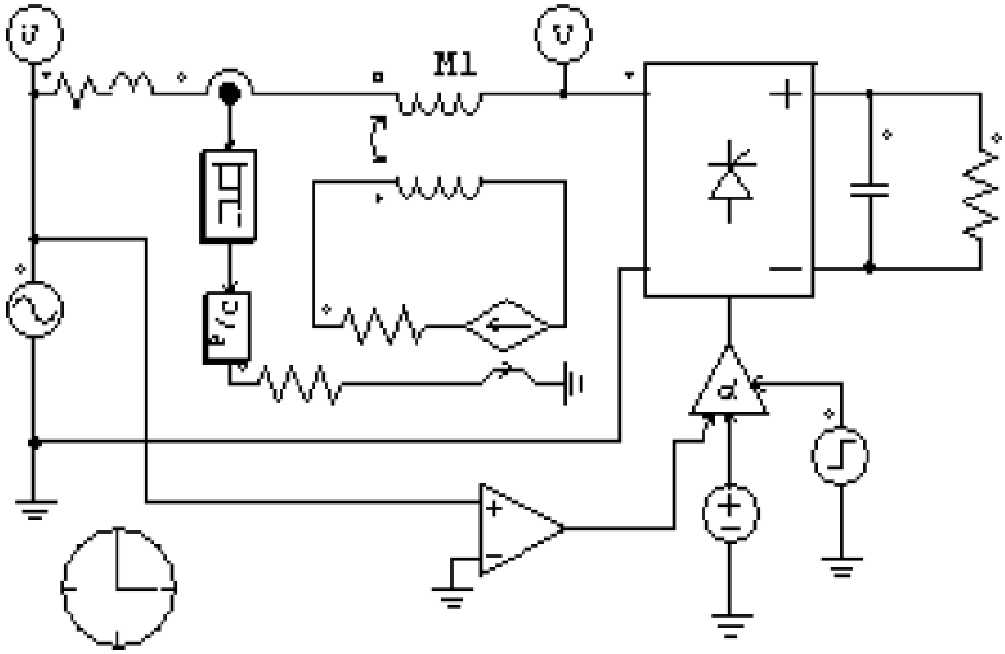

Fig. 8: Simulation model of the novel series active power filter

Fig. (9) shows the source current when the firing angle equals to zero degree and in this case no filter is added. While Fig. (10) shows the source current waveform when the firing angle equals zero degree and in this case the novel active power is applied here.

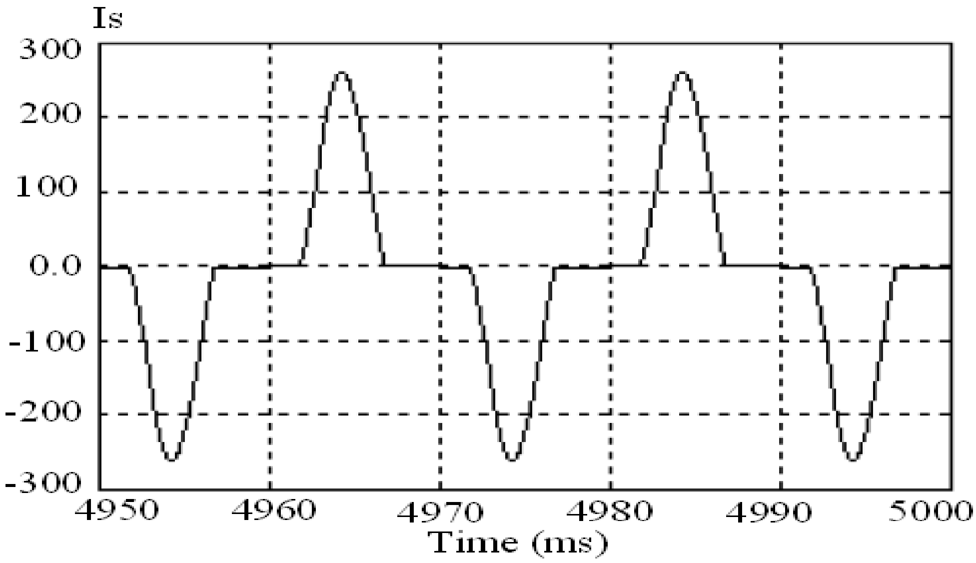

Fig. 9: The source current waveform when the firing equals 0 degree and no filter is added

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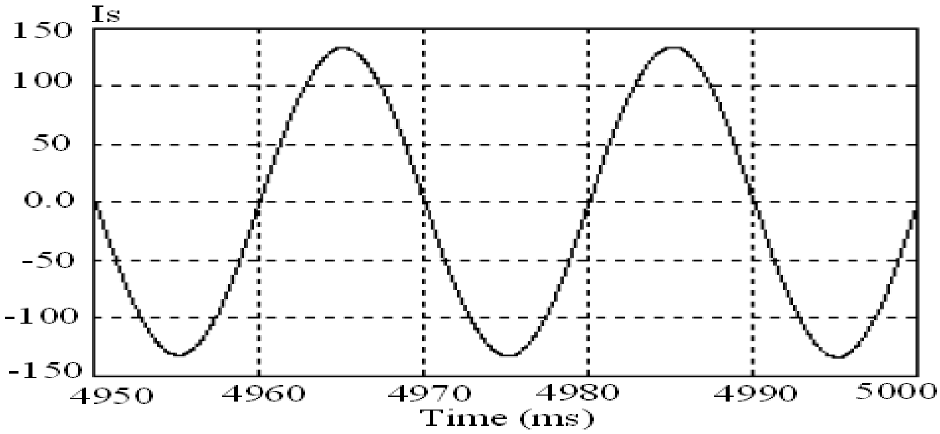

Fig. 10: The source current waveform when the firing equals 0 degree and the novel active power filter is applied

Fig. (11) shows the source current when the firing angle equals to 60 degree and in this case no filter is added. While Fig. (12) shows the source current waveform when the firing angle equals 60 degree and in this case the novel active power is applied here.

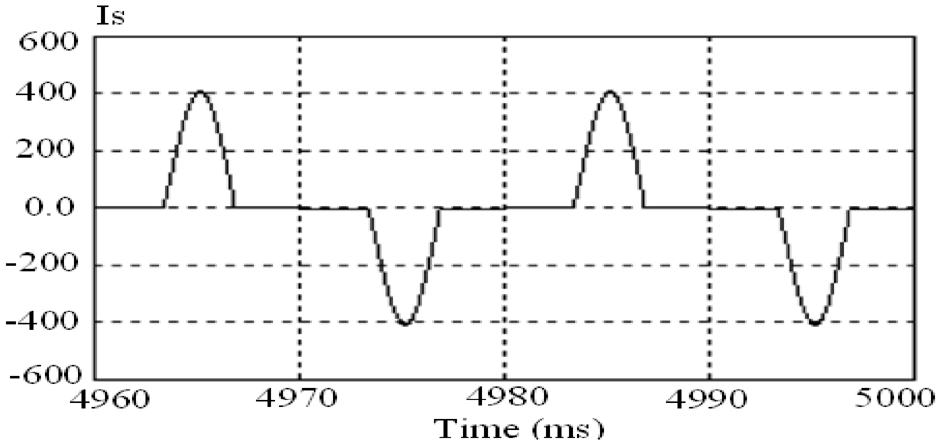

Fig. 11: The source current waveform when the firing equals 60 degree and no filter is added

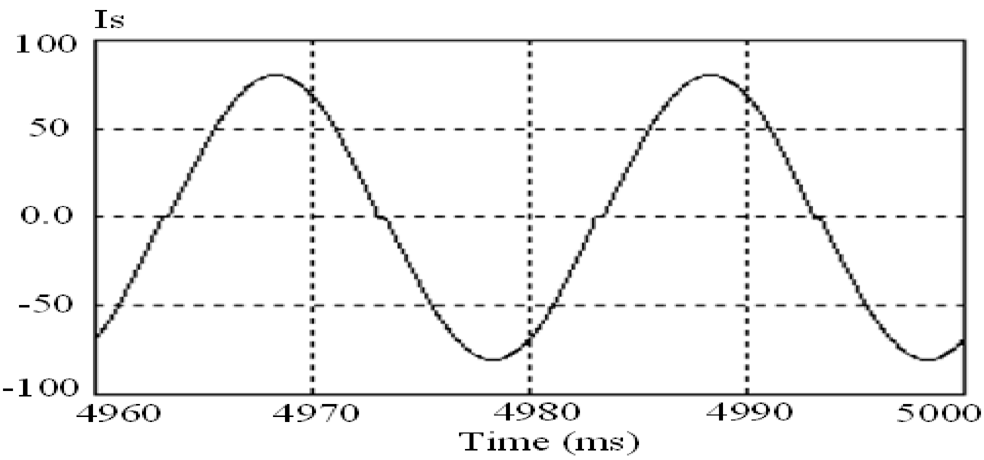

Fig. 12: The source current waveform when the firing equals 60 degree and the novel active power filter is applied

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VI.CONCLUSION

In this paper, the physical essential of the two types of harmonic sources is firstly analyzed and explained by simulation results. And then a novel series active power filter is proposed when the load is voltage type harmonic source. The difference between the proposed active power filter and the active power filter with FMFC is that the proposed active filter is without passive filter and the proposed active filter is only suitable for the filtering of the voltage type harmonic source. The novel series active power filter is with smaller bulk and lower cost. The main circuit and filtering principle are analyzed in detail in the paper. The simulation model of the active filtering system is established while the load is voltage-type harmonic source and the filtering simulation results are given. The simulation results verify the principle analysis.

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