ISSN 1009 - 3095 *Journal of Zhejiang University(SCIENCE)* V.1, No.4, P.394 - 397, Oct. - Dec., 2000
http://www.chinainfo.gov.cn/periodical; http://www.zju.edu.cn;
http://lib.zju.edu.cn/English; http://www.zjupress.com

A NEW STRUCTURE OF SERIAL HYBRID ACTIVE POWER FILTER FOR HIGH POWER APPLICATION*

CHEN Guo-zhu(陈国柱)†, LU Zheng-yu(吕征宇), QLAN Zhao-ming(钱照明)
(*Electrical Institute of Zhejiang University, Hangzhou, 310027, China*)
† E-mail: gzchen@cee.zju.edu.cn

Received Aug.28, 1999; revision accepted Apr.15, 2000

Abstract: This paper proposes a new structure of serial hybrid active power filter which can reduce the power rating of the active power filter dramatically, and has good performance for harmonic suppression. The principle and designing rules are analyzed. The proposed structure is rational and feasible for high kVA applications. Simulation results are presented too.

Key words: active power filter, harmonics, power conditioning, power quality
Document code: A **CLC number:** TM714

INTRODUCTION

To cope with the more and more serious harmonic problems mainly caused by power electronic equipment application, various kinds of active filters have been proposed and put into field applications recently. Among them, a Serial Hybrid Active Power Filter (SHAPF) as shown in Fig.1 (exclude the dotted box) is particularly attractive due to its low cost, good performance, multi-function and small rating serial active power filter (APF, typically 5% of the load). It presents a resistance k to harmonic current and a low resistance to fundamental component (Chen et al., 1998; Peng et al., 1988)

However, it is clear that when the system power rating is high, the Voltage Source Inverter (VSI), the APF, has to deliver not only the harmonic power but certain amount of fundamental power components too. This causes high demand for a large power rating of VSI. It is difficult to protect the APF inverter too due to its serial structure. These actually limit the SHAPF application. For this reason, only one power system application in U.S.A has been reported (Bhattacharga et al., 1995).

PRINCIPLES AND ANALYSIS

A fundamental frequency tuned L-C filter with notch impedance character is proposed (Fig.1) for preventing current coupled from the main circuit from impacting on the VSI. By detailed design, it acts as a sink for the fundamental current and voltage from the main side and the APF inverter respectively.

Where, PPF1 is the fundamental frequency tuned L - C branch proposed by this paper; PF is a set of passive filters, such as 5th, 7th and so on, and a high pass one; $\boldsymbol{V}_c$, $\boldsymbol{V}_r$ are the output voltage vectors of the APF and VSI respectively; $\boldsymbol{Z}_r$ is the equivalent impedance of VSI including a low pass filter. In Fig.1 hereafter $\boldsymbol{V}$, $\boldsymbol{I}$, $\boldsymbol{Z}$ represent voltage, current and impedance of the branches; Subscripts S, L, F, r and p represent the branches source, load, PF, VSI and PPF1 respectively.

1. Design considerations

For the aim that most fundamental current coupled from the main side sink into PPF1 and without causing high fundamental voltage or increasing harmonic current supplied by the VSI, it has to comply with the following conditions:

$$\begin{cases} |\boldsymbol{Z}_P(\omega_0)| = R \ll |\boldsymbol{Z}_r(\omega_0)| \\ |\boldsymbol{I}_P(\omega_0) \cdot \boldsymbol{Z}_P(\omega_0)| \to L_{s1} \times \omega_0 \times \boldsymbol{I}_s(\omega_0)/n \to 0 \\ |\boldsymbol{Z}_P(\omega_h)| \gg |j\omega_h \times L_{s1} + \boldsymbol{Z}_1(\omega_h)| \gg |\boldsymbol{Z}_r(\omega_h)| \end{cases} \quad (1)$$

* Project supported by DELTA Science, Technology and Education Development Foundation for Power Electronics of China.

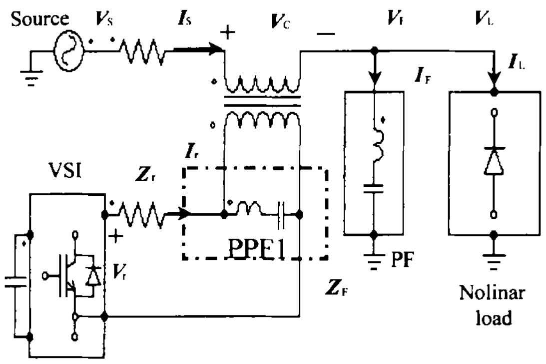

Fig. 1 Proposed serial hybrid active power filter (SHAPF) for high power application

Where ω_0, ω_h are fundamental and harmonic frequencies; $Z_P(\omega_0)$ is impedance of the PPF1 tuned L - C branch; n is the transformer ratio; R is the equivalent resistance of the tuned PPF1; L_{s1} is the primary leakage inductance of the transformer. $Z_1(\omega_h)$ is the equivalent impedance to harmonics of the transformer converted from the main side. Here $|j\omega_h \times L_{s1}| \gg |Z_1(\omega_h)|$ is usually tenable for the main source and the PF.

By using Equation (1), the current of the inverter (VSI) can be calculated as:

$$\begin{aligned} I_r &= I_r(\omega_0) + I_r(\omega_h) \\ &= \frac{Z_P(\omega_0)}{Z_P(\omega_0) + Z_r(\omega_0)} I_s(\omega_0)/n + \\ &\quad \frac{V_r(\omega_h)}{Z_r(\omega_h) + Z(\omega_h) + Z_P(\omega_h) // j\omega_h L_{s1}} \\ &\approx I_r(\omega_h) \end{aligned} \tag{2}$$

Where Z_r is the output current and voltage of the Current Controlling Voltage Source (CCVS), that is the VSI, controlled by residual harmonic current of the source branch ($I_s(\omega_h)$ with gain G. I_r is the current supplied by the VSI .

Equation (2) shows that the fundamental current component flowing into/out of the VSI is almost eliminated if $Z_P(\omega_0) | \ll | Z_r(\omega_0)$.

2. The harmonic suppression performance

An equivalent circuit (Fig. 2) was used to investigate the transfer function $H_I(j\omega)$. Equations (3) and (4) for fundamental (ω_0) and Equation (5) for harmonics (ω_h) can be derived as follows:

For fundamental

$$\begin{cases} V_c(\omega_0) = I_s(\omega_0) \cdot j\omega_0 L_2 + I_t(\omega_0) \cdot j\omega_0 M \\ I_p(\omega_0) \cdot Z_p(\omega_0) \\ \quad = I_t(\omega_0) \cdot j\omega_0 L_1 + I_s(\omega_0) \cdot j\omega_0 M \\ I_t(\omega_0) + I_p(\omega_0) = I_r(\omega_0) \approx 0 \end{cases} \tag{3}$$

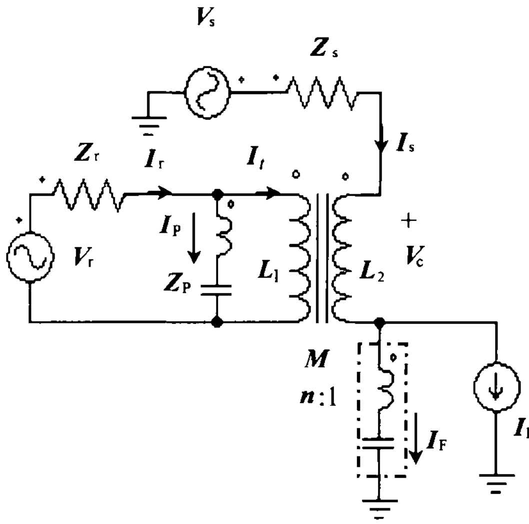

Fig. 2 The equivalent circuit of proposed SHAPF

we can get

$$H_I(j\omega_0) = \frac{V_c}{I_s} = \frac{Z_p(\omega_0)}{n^2} \tag{4}$$

For harmonics

$$\begin{cases} V_c(\omega_h) = I_s(\omega_h) \cdot j\omega_h \cdot L_2 + I_t(\omega_h) \cdot \\ \quad j\omega_h M \\ V_{rh} = G \cdot I_s(\omega_h) \cdot I_r \cdot (Z_r + \omega_h \cdot L_1) + \\ \quad I_s(\omega_h) \cdot M\omega_h \\ I_t(\omega_h) = I_r(\omega_h) = \dfrac{G - M\omega_h}{Z_r(\omega_h) + \omega_h \cdot L_1} \cdot \\ \quad I_s\omega_h) \end{cases}$$

$$\begin{aligned} H_I(j\omega_h) &= \frac{V_c}{I_{sh}} \\ &= \frac{G - M\omega_h}{Z_r(\omega_h) + \omega_h \cdot L_1} M \cdot \omega_h + \omega_h L_2, \end{aligned}$$

Using $M = \sqrt{L_1 L_2}$ and $L_1 = n^2 \cdot L_2$

$$H_I(j\omega_h) = \frac{G}{n} \equiv K \tag{5}$$

From Equations (4) and (5), we can conclude:

This structure SHAPF has the same transfer function for harmonics control as that reported in literature (Peng et al., 1988; Bhattacharya et al., 1995). It acts as a harmonic isolator with equivalent resistance K.

SHAPF with extremely low resistance to fundamental current can be produced by proper design.

3. The rating and protection of the VSI

The three phase APF-VSI's rating is determined by

$$S_r = |V_r| \times |I_r| \times 3 \tag{6}$$

Here $V_{rh} = G \cdot I_s(\omega_h)$, and I_r is given by Equation (2). To achieve the same system suppression performance, residual harmonic current $I_s(\omega_h)$, under the conditions of Equation (1), we can find that the first term of Equation (2) is reduced by $\frac{Z_p(\omega_0)}{Z_p(\omega_0) + Z_r(\omega_0)}$, while the second term is almost constant in the application of the proposed SHAPF. What is more, the first term of the Equation (2) is usually much larger than the second term in a conventional SHAPF ($Z_p \to \infty$). That is to say that the rating of the VSI without this structure is mainly fundamental, and it is sharply reduced by the proposed SHAPF. Also, the S_r is reduced dramatically.

With the PPF1 providing a fundamental channel for the main coupled current, this SHAPF structure can easily protect the VSI from over – current, and can provide uninterrupted power supply to the load when the VSI faults. This was one of the difficulties limiting the SHAPF actual application formerly (S. Bhattacharya, 1995).

SIMULATION RESULT

To test the aforementioned rules and principles, a detailed simulation was done over the set of parameters below.

Load rating 50 kVA/380V 3Φ;

Transformer ratio $n = 10:1$;

PPF1 branch:

$$Z_p = 0.2 + j\left(\omega \cdot 30mH - \frac{1}{\omega \cdot 338\mu F}\right)\Omega,$$
$$Q \approx 50$$

Some results are shown as follows:

Fig. 3 shows us that the new structure SHAPF has the same good performance for harmonic suppression as the harmonic suppressor systems reported in literature (F.Z.Peng et al., 1988, S. Bhattacharya et al., 1995).

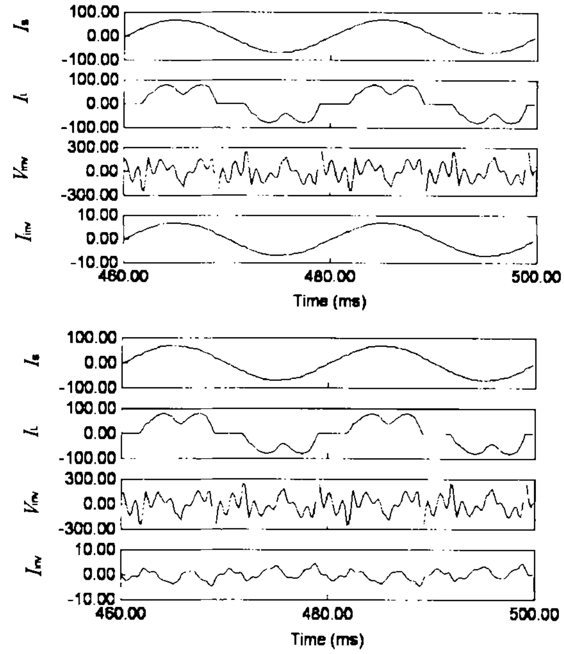

Fig.3 SHAPF harmonic suppression simulation From top to bottom: source current I_s, load current I_L, inverter output voltage $V_{inv}(V_r)$, inverter current $I_{inv}(I_r)$ (a) Conventional SHAPF; (b) SHAPF with proposed structure

From Fig.4, we can see that the VSI fundamental current is greatly reduced from 6.7A to 0.36A with the proposed structure. The losses,

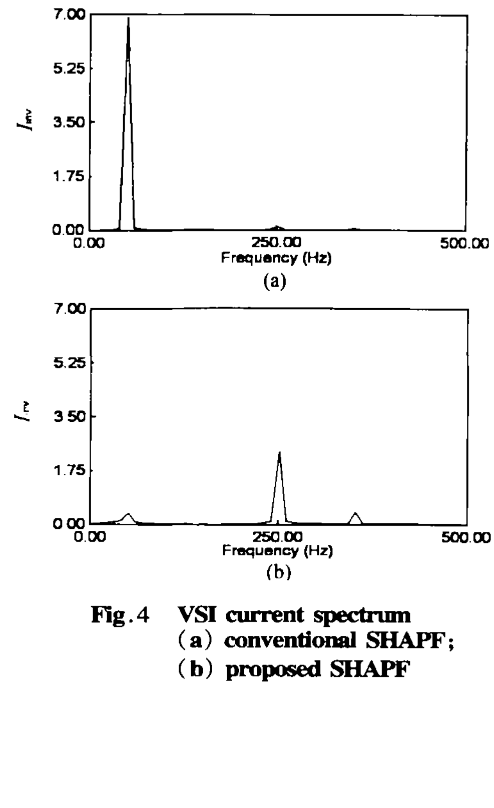

Fig.4 VSI current spectrum (a) conventional SHAPF; (b) proposed SHAPF

which are square functions of the current, sharply drop down. Although the harmonic current of the VSI is increased a little, it is not very serious. Especially in higher power system this small increase can be ignored.

If this structure SHAPF is applied to higher power rating system, for a 10 MVA system, for example, the rating of the VSI can be reduced from the typical 500kVA to 20 – 30 kVA. Which is valuable in practical applications.

CONCLUSIONS

The new structure serial SHAPF and its designing rules are presented in this paper. Analysis and simulation results showed that this SHAPF has good performance for harmonic suppression. It is simpe but can reduce the APF inverter's power rating and reduce energy losses and cost significantly. The new SHAPF can give highly reliable protection against harmonic currents. It is suitable for high power application.

References

Akagi H.. H., Fujita, 1995. A New Power Line Conditioner for Harmonic Compensation in Power Systems, *IEEE – PWRD*, **10**(3):1570 – 1575.

Bhattacharya S., Divan D. M., 1995. Design and Implementation of a Hybrid APF, *In*: APEC'1995 Conference Record, USA. p. 189 – 195.

Cheng PoTai, Bhattacharga S., Divan D. M., 1996. Hybrid Solution for Improving Passive Filter Performance in High Power Applications, *In*: APEC'96 Conference Record, USA, p. 911 – 917.

Chen Guozhu, Lu Zhenggu, Qian Zhaoming, 1998. A Hybrid Solution to Active Power Filter for the Purpose of Harmonic Suppression and Resonance Damping, *In*: Proc. of Power Con'98 Beijing, China, p. 1542 – 1546.

Chen Guozhu, Lu Zhengyu, Qian Zhaoming, 1999. The harmonic pollution report of the industry adjustable speed system, *In*: Proc. of the national 5th EMC conference ('99EMC Beijing), China. p. 210 – 216 (In Chinese, with English abstract).

Fujita H., Akagi H., 1990. A Practical Approach to Harmonic Compensation in Power Systems, *In*: IEEE – IAS Annual Meeting, Conference Record, USA. p. 1107 – 1112.

Peng F.Z., Akagi H., Nabae A., 1988. A New Approach to Harmonic Compensation in Power System, *In*: IEEE – IAS Conference Record, p. 874 – 880.