An Improved Transformerless Hybrid Active Power Filter with Adjustable Reactive Power Compensation Capability

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Abstract

This paper presents a new control scheme for the conventional transformerless hybrid active power filter (HAPF). This HAPF is intended for harmonic and reactive power compensation. The main difference between this control scheme and the classical control methods is that it can compensate the reactive power dynamically. The effectiveness of the proposed control scheme has been verified using computer simulation.

1. Introduction

Harmonic suppression and reactive power compensation are important issues in power systems today. The harmonic current will pollute the power system and result in serious problems such as transformer overheating, increased system losses and significant interface with communication circuits. Also reactive power will decrease power factor and the active power supplied from utility side. To avoid such undesirable effects, traditional solution using passive filters (PF) have been used. The main advantage of LC filters is high reliability and low cost. However they have several drawbacks such as series and parallel resources with the utility, bad filtering performance under the variation of source impedance and attraction of harmonic currents from ambient harmonic loads [1, 3].

In order to overcome these problems an effective method of harmonic suppression and reactive power compensation with active power filters (APF) has been proposed. But in APFs the DC link capacitor voltage is required to be higher than the peak value of source voltage, for high power application. The required high DC link voltage restricts the APFs implementation due to increase in the losses, rating and the total cost of the APF [4, 6].

In recent years, hybrid active power filters (HAPF) have been proposed which combines the advantages of PFs and APFs. HAPSs have the following advantages [7, 9]:

1) They prevent series or parallel resonances between PFs and system impedances.
2) The voltage rating of APF is reduced considerably thus reducing cost of whole system.

Fig. 1 shows the HAPF topology and power circuit studied in [10]. The PF is tuned at seventh harmonic and its purpose is to impose high impedance to the fundamental frequency, so that

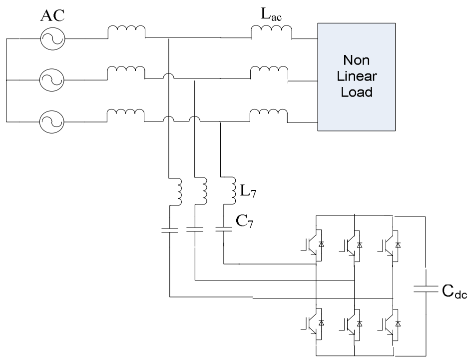


Fig. 1. Power circuit of the HAPF

the source voltage appears exclusively across the capacitor thus there is no need to install coupling transformer to decouple APF from utility. The main function of APF is to suppress harmonic currents introduced by nonlinear load. The main disadvantage of this HAPF is that it injects fixed reactive power thus utility power factor can’t be compensated dynamically. Fig 2 shows the scheme of classic control method applied to HAPF proposed in [10]. In this paper, an improved HAPF is proposed which can suppress the harmonic currents and compensate reactive power dynamically. An extra voltage is built with APF to inject required reactive power to maintain utility power factor nearly unity.

2. Proposed control method

2.1. Current harmonic compensation

In the current harmonic compensation mode, the active power filter improves the filtering characteristic by imposing a voltage harmonic waveform at its terminals with amplitude equals to:

$$V_{AF} = KI_{SH} \tag{1}$$

Where I_{SH} is the harmonic content of the line current to be compensated and K is the APF gain. If the source voltage is purely sinusoidal, the ratio between the harmonic component of nonlinear load and the harmonic component of ac line current is obtained from Fig. 3(a) and equals to:

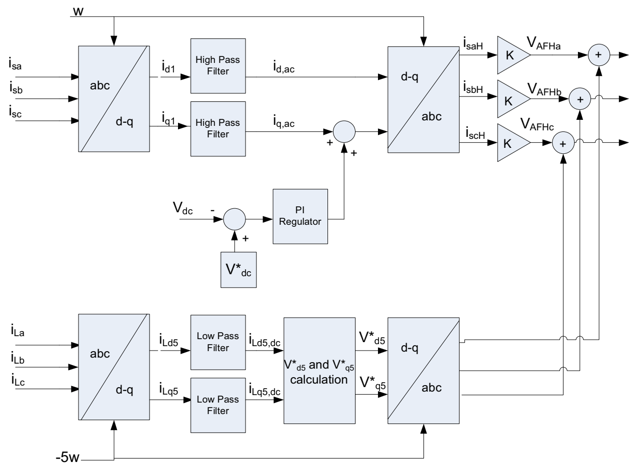


Fig. 2. Conventional control scheme block diagram

$$\frac{I_{SH}}{I_{LH}} = \frac{Z_f}{K + Z_f + Z_S} \tag{2}$$

Equation 2 shows that the attenuation of load current harmonics depends on the value of the passive filer equivalent impedance Z_f, the APF gain K, and the system impedance Z_S. To improve compensation performance, K must be increased because Z_S and Z_f are constant.

2.2. Reactive power compensation

Fig. 3(b) shows the equivalent circuit of the system under fundamental frequency. To adjust the generated fundamental reactive current, the APF must generate a fundamental voltage whose phase is the same as that of source voltage and its magnitude can be controlled as a factor of K_q of the system voltage. The fundamental V_{CPF} across the capacitor can be represented as:

$$V_{C_{PF}} = V_L - V_{AFf} = (1 - K_q)V_L \tag{3}$$

$$I_{HF} = j\frac{V_{C_{PF}}}{X_C} = j\frac{V_L}{X_C}(1 - K_q) \tag{4}$$

The reactive power generated by the HAPF can be represented as:

$$Q_{Hf} = V_L I_{Hf} = Q_{PF}(1 - K_q) \tag{5}$$

From (5) it can be found that the HAPF can inject or absorb adjustable reactive power by controlling K_q.

3. Proposed control block diagram

Fig. 4 shows proposed control scheme block diagram of HAPF. It consists of two main loops named as feedback and feedforward control loop. In feedback control loop three phase measured source currents are transformed to synchronous reference frame rotating at fundamental angular speed. It converts them in to two phase currents named as i_{d1} and i_{q1}. Harmonic components of source currents, $i_{d,ac}$ and $i_{q,ac}$ are extracted using two high pass filters. The error of DC link voltage is fed to a PI controller to maintain it at desired value.

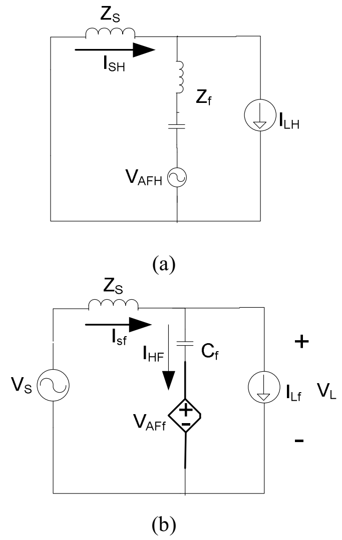


Fig. 3. Single-phase equivalent circuit of the HAPF. (a) For current harmonic compensation. (b) For reactive power compensation

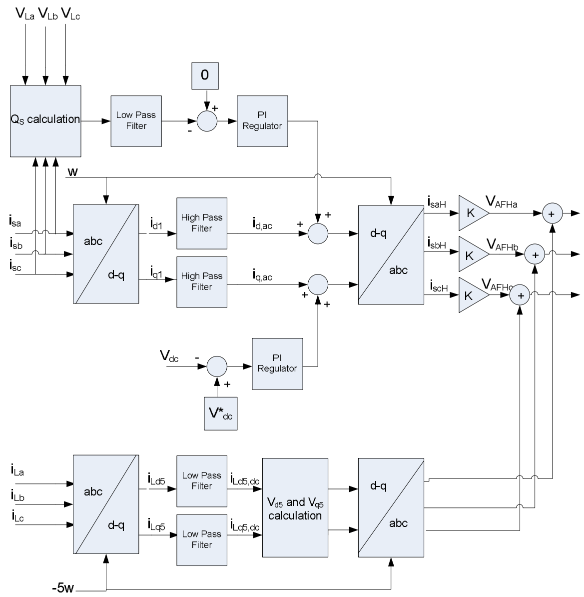


Fig 4. Proposed control scheme block diagram

Another loop is added to feedback control loop in d axis to inject adjustable reactive power to system. This will allow source currents be in phase with source voltages. Source reactive power is obtained as bellow:

$$Q_S = \mathrm{Im}(V_L I^*_S) \tag{6}$$

Q_S is passed from a low pass filter to obtain the DC value of reactive power then it is compared with its reference value. The error signal is fed to a PI controller. The result signal is added to

i_d current to produce required command for reactive power compensation. Finally inverse transformation produces the source harmonic currents and each phase harmonic current is amplified by a gain of *K*.

In feedforward control loop the measured three-phase load currents are transformed to reference frame rotating at fifth harmonic frequency. The fifth harmonic current presents in load current correspond to $i_{Ld5,dc}$ and $i_{Lq5,dc}$ are obtained using two low pass filters each tuned at the same cut-off frequency. The feedforward voltage reference is obtained by:

$$\begin{bmatrix} v_{d5}^* \\ v_{q5}^* \end{bmatrix} = \begin{bmatrix} R_F & -\omega_5 L_F + \dfrac{1}{\omega_5 C_F} \\ \omega_5 L_F - \dfrac{1}{\omega_5 C_F} & R_F \end{bmatrix} \begin{bmatrix} i_{Ld5,dc} \\ i_{Lq5,dc} \end{bmatrix} \quad (7)$$

The inverse transformation provides feedforward voltage reference which is added to feedback reference voltage.

4. Simulation results

The efficiency of the proposed control method has been examined by computer simulation using Matlab and associated toolbox "Simulink" and "Power System Blockset". The main parameters of the system are given in table 1. The load used in the following simulations is three-phase diode rectifier with a dc inductance, a dc capacitor and a resistor.

Fig. 5 shows the simulation results of HAPF with proposed control scheme. As seen in Fig. 5, the load current is seriously distorted and it demands significant reactive power from source. The load current is nearly sinusoidal and also DC link voltage is well regulated at 300 V. Fig. 6 shows the frequency spectrum of the load current and the source current. The total harmonic distortion (THD) of the load current is 23.62%, and the THD of source current is 2.16%. Fig. 7 shows reactive power compensation capability of the proposed control method. As seen in Fig. 7 the reactive power is nearly compensated that increases source power factor.

The main feature of the proposed control scheme is that it can compensate reactive power even under dynamic changes is occurred in the load and reactive power. Thus the efficiency of proposed control scheme is verified under load step change.

Fig. 8 shows the simulation results of HAPF when step load change is occurred. It can be seen that the source current reaches its steady state value after one cycles and also the DC link voltage is well regulated during and after the transient state because the DC voltage control provides critically damped PI regulator.

Fig. 9 shows the simulation results for the reactive power compensation. It is seen that a large amount of reactive power is compensated dynamically by HAPF with the proposed control method.

However the proposed control scheme gives good results for both harmonic and dynamic reactive power compensation.

Table 1. Main parameters of the system

V_{sa} , f_s	325 V (peak), 50 H
L_7 , C_7	2 mH, 100 µf
f_{pwm}	10 KH
V_{dc} , C_{dc}	300 V, 3000 µf

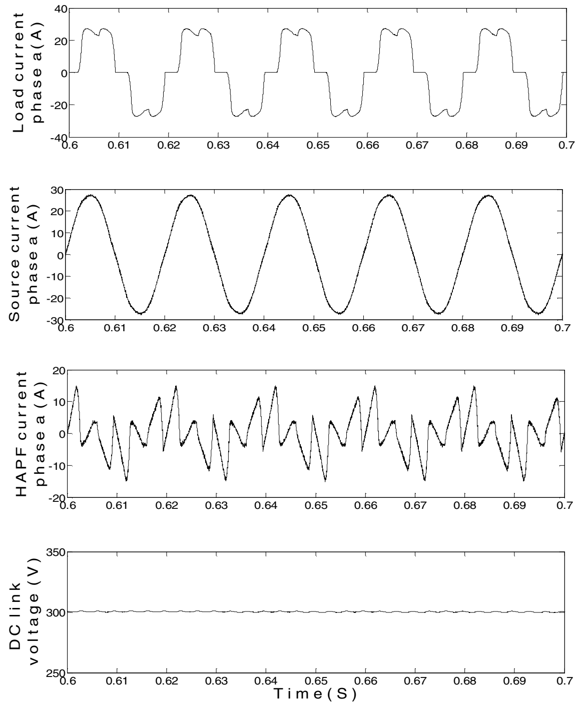
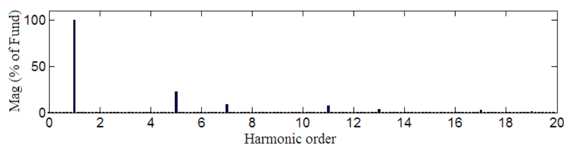
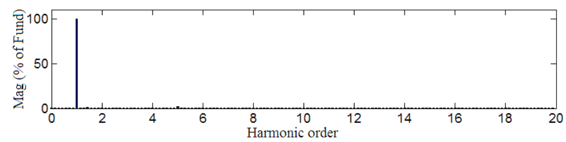


Fig. 5. Simulation results of HAPF with proposed control method



(a)



(b)

Fig. 6. Frequency spectrum of the load and source current: (a) For load current. (b) For source current.

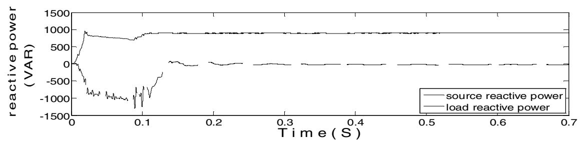


Fig.7. Source and load reactive power

It is noticed that with higher DC link voltage, harmonic and reactive power compensation can be done better but this increases the APF voltage rating. Although the DC link voltage is higher than that implemented in [10], but still it is lower than source peak voltage because of PFs which are connected in series with each phase of APF and decouple fundamental voltage from APF. In this paper the value of DC link voltage is an agreement between load reactive power compensation and increasing APF VA rating.

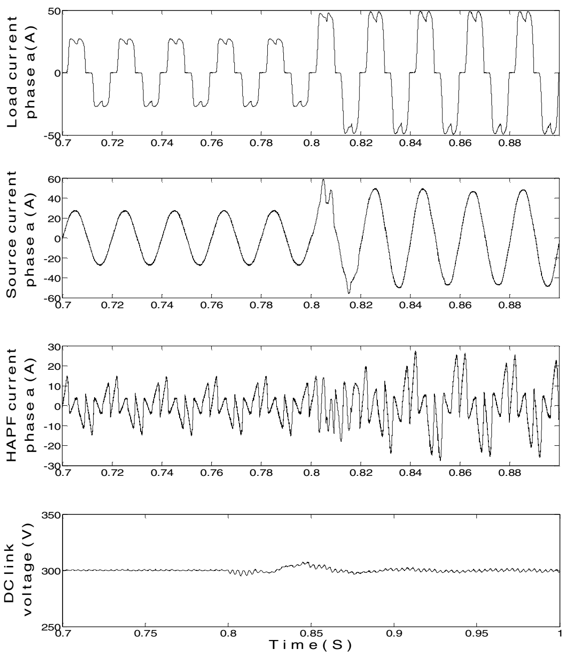


Fig. 8. Simulation results of HAPF under the step load change

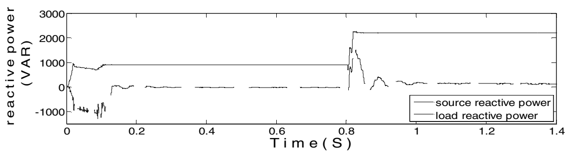


Fig. 9. Source and load reactive power under the step load change

5. Conclusion

In this paper a new control scheme for transformerless HAPF is proposed which enables HAPF to compensate reactive power, dynamically. The computer simulation results verify that the proposed control method has the expected performance.

7. References

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