A Novel Hybrid Active Filter for Power Quality Improvement and Neutral Current Cancellation

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Abstract

In this paper a new hybrid active filter is proposed that combines harmonic filtering and neutral current compensation. The main difference between proposed topology and conventional structures consists of the connection of neutral wire to positive terminal of DC link capacitor thus avoiding the need of split capacitor or forth leg for neutral current cancellation that reduces the manufacturing cost. A simple control method based on damping resistor is used to achieve desired harmonic compensation and neutral current cancellation. Simulation results show that proposed hybrid active filter has the expected performance.

1. Introduction

Three-phase four-wire power distribution systems are widely used to supply nonlinear loads. The existence of nonlinear loads in the utility has been increasing at an unprecedented pace in recent years. Industries have adopted adjustable speed drives, dc power supplies to improve efficiency and productivity. Most of the equipments use a rectifier front end to convert ac power from the source to dc power. The rectifier front ends inject harmonic current into utility due to their nonlinear nature and cause many problems, such as overheating of utility transformers, harmonic resonances in the utility and increased losses. The third harmonic is most serious when nonlinear loads are single phase that will cause zero sequence current flows through neutral current which may damage neutral conductor.

Traditionally, LC tuned passive filters have been used to absorb harmonic currents generated by nonlinear loads. Their main advantages are high reliability and low cost. However they have several drawbacks [1, 3]:

1) Mistuning occurs due to component tolerances of the inductors and capacitors.

2) The LC tuned passive filter may form series and parallel resonances with the utility.

3) The filter frequency is fixed, and not easy to adjust.

In recent years active power filters have been proposed which can overcome above problems of passive filters but their capability is limited by switching device and are not cost effective due to their large rating and high frequency switching requirement of PWM inverter [4, 6]. Hybrid active filters are developed to solve the active power filter as well as passive filters [7, 10]. Fig. 1 shows schematic circuitry of the conventional hybrid power filter which consists of a series passive filter and an active power filter. The passive filter is used to reduce the rating of the active power filter. In such structures, the role of the active part is basically the harmonic cancellation. In three-phase four-wire systems when three single-phase nonlinear load are connected to each phase of system, then zero sequence current follows in neutral wire. In this situation the three-phase four-wire system requires hybrid active filter using a four-leg inverter bridge. Three-leg power converter configuration with split capacitors and four-leg power converter topology are popular configurations of three-phase four-wire hybrid active filters [11]. Although the three-leg four-wire hybrid active filters will save power switches, but this solution is however more costly, bulky, and requires a constant balancing of the DC voltages across the capacitors, which increases the control complexity.

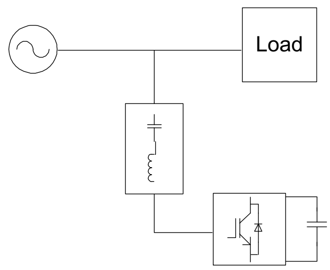

Fig. 1. Conventional hybrid active power filter

In this paper a new hybrid active filter is proposed which is suitable for the three-phase four-wire systems. The novelty of the proposed hybrid active filter is the fourth wire that is directly connected to the positive or negative terminal of DC link capacitor to compensate neutral wire current. A simple frequency domain control method based on damping resistor is used to control the active part [12] and also the most dominant harmonic currents such as third and fifth harmonics are compensated with passive power filters.

2. Proposed three-phase four-wire hybrid active filter

Fig. 2 shows the proposed hybrid active filter which is configured by series combination of the active and passive filtes.

The small rated active part consists of a three-leg four-wire PWM inverter and the forth wire which compensates for neutral current, is connected between system neutral wire and positive terminal of the DC link voltage. This means that this power converter can omit a pair of power electronic switches when compared with the conventional four-leg bridge structure, or this power converter can omit a DC capacitor and solve the problem of voltage balance when compared with bridge configuration with split capacitors [11]. Two passive filters each are tuned at third and fifth harmonic frequencies are connected in series with each phase of the active part and cause the fundamental voltage is decoupled from the source side thus reducing voltage rating of active power filter.

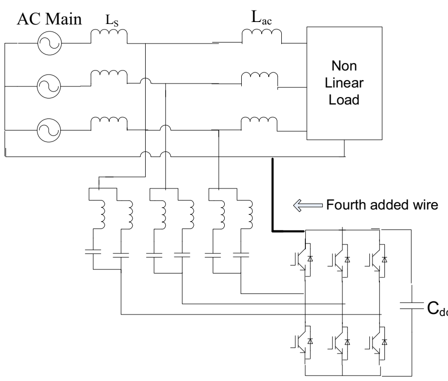

Fig. 2. Three-phase four-wire hybrid power filter topology

3. Compensation principle

The principle of compensation for current harmonic and reactive power is explained with the help of two single phase equivalent circuits shown in Fig. 3.

3.1. 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:

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

Where I_{SH} is the harmonic content of the line current to be compensated and K is the active power gain. If the source side 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:

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

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

3.2. Reactive power compensation

Fig. 3(b) shows the equivalent circuit of the system under fundamental frequency. Since the main function of the active filter is to compensate harmonic current thus power converter can be considered as a short circuit under fundamental frequency. Compared with the impedance of capacitor, the impedance of inductor is very low and it can be neglected. Hence the fundamental voltage drops across the capacitor that can supply the fixed reactive power which is approximated as:

$$Q_c \approx 3\omega C V_s^2 \tag{3}$$

Where C is the equivalent capacitor of passive filters and V_s is the root-mean square (rms) value of the source voltage. The reactive power demanded by the load is shared between the two capacitors respective to their MVA rating. After determining capacitors value from the reactive power assigned them, the related inductors of each passive filter can be determined as bellow:

$$L_{fm} = \frac{1}{(2\pi f . m)^2 C_{fm}} \tag{4}$$

Where m= 5, 7. It should be noticed that a high value of C_{fm} reduces impedance at fundamental frequency resulting in passage of fundamental frequency (f) current, which is highly undesirable. Also a low value results in a bulky inductor in the resonant branch, which in turn increases its cost.

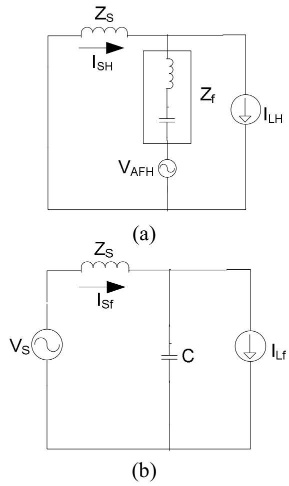

Fig. 3. Single-phase equivalent circuit of the hybrid power filter. (a) For current harmonic compensation. (b) For reactive power compensation

4. Control block diagram

The control block diagram is shown in Fig. 4 which consists of a feedback control loop. Because third and fifth tuned passive filters are used in the proposed hybrid active filter, there is no need to control fifth harmonic using feed forward control loop. The three-phase source current is sensed and transformed to d-q coordinates which converts it to ac and dc components. Passing these components through two low pass filters and subtracting these filtered signals from the non filtered signal will result in ac

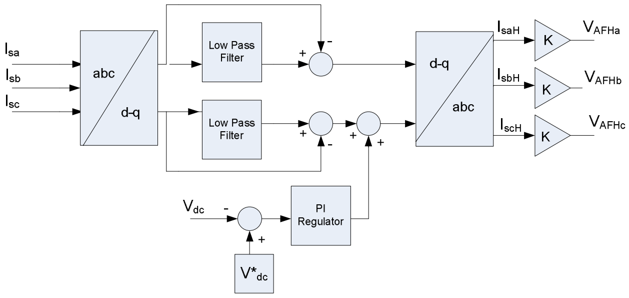

Fig. 4. Control block diagram

components in *d-q* frame. By transferring these ac components to *a-b-c* frame, harmonic current components will be achieved. The capacitor voltage is measured and compared with the reference voltage. Error signal is fed to a PI controller in order to maintain it at a desired value.

5. Simulation results

The efficiency of the proposed hybrid active filter 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 loads used in the following simulations are three single-phase rectifier loads which are connected between every phase and neutral. Fig. 5 shows the simulation results of the nonlinear load currents.

Table 1. Main parameters of the system

V_{sa} , f_s	320 V (peak), 50 Hz
(L_3 , C_3), (L_5 , C_5)	(10 mH, 88.8 μf), (16 mH, 25 μf)
V_{dc} , C_{dc}, f_{pwm}	120 V , 9800 μf, 10KHz

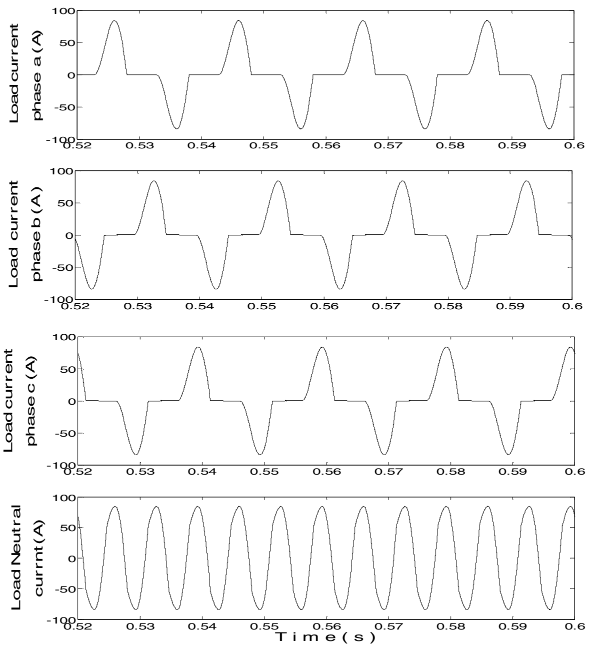

Fig. 5. Simulation result of the nonlinear load currents

It is seen that load currents are full of harmonic and the amplitude of its neutral current is very high. The RMS value of neutral current is 63.32 A. Fig. 6 shows the frequency spectrum for the load current of phase a. As seen in Fig. 6 the load current is seriously distorted and the THD is 67.89%. Fig. 7 shows the source currents after compensation using the proposed hybrid active filter. It is seen that the source currents are nearly sinusoidal and the neutral current has been suppressed to a very low value and its RMS is 2.3 A. Fig. 8 shows the frequency spectrum for source current of phase a. The THD of supply current is reduced to 4.53 A. Fig. 9 shows DC link voltage and three-phase power converter output currents under the steady states. From Fig. 9, the DC link voltage of power converter is well controlled and regulated nearly

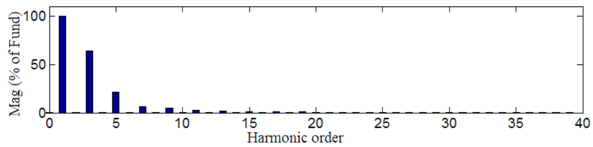

Fig. 6. Frequency spectrum of the load current of phase a

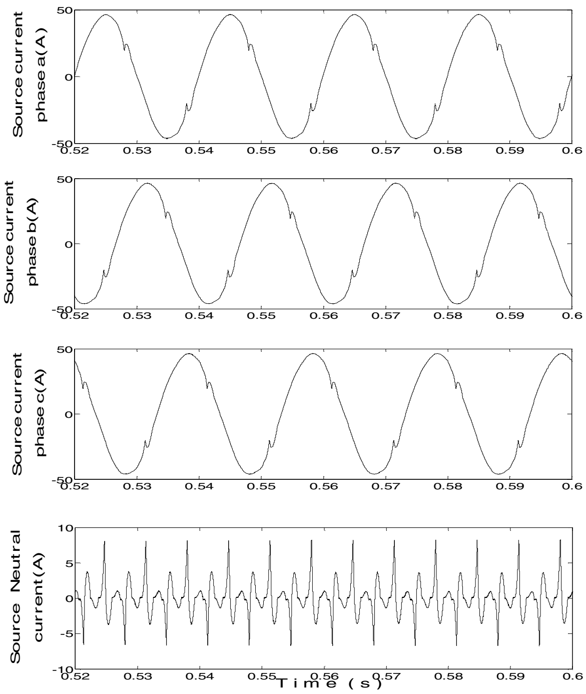

Fig. 7. Simulation result of source current after compensation by hybrid filter

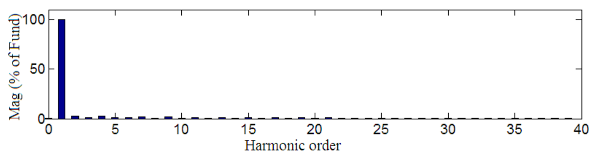

Fig. 8. Frequency spectrum of the source current of phase a

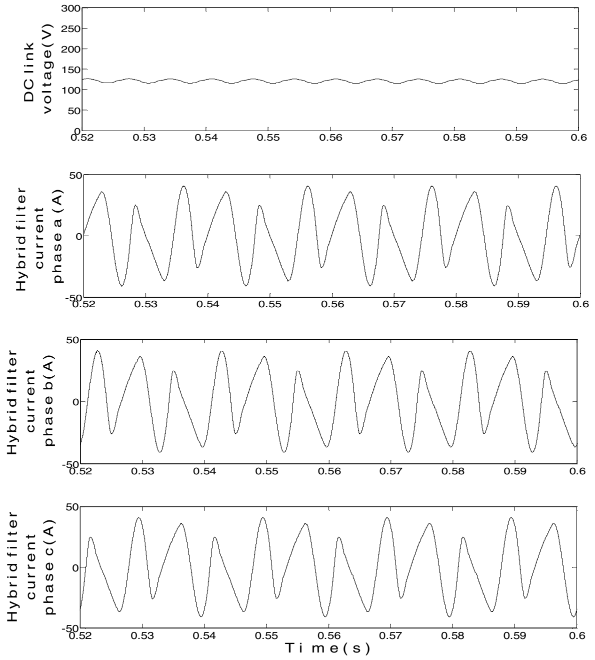

Fig. 9. Simulation results of DC link voltage and three-phase hybrid active filter currents

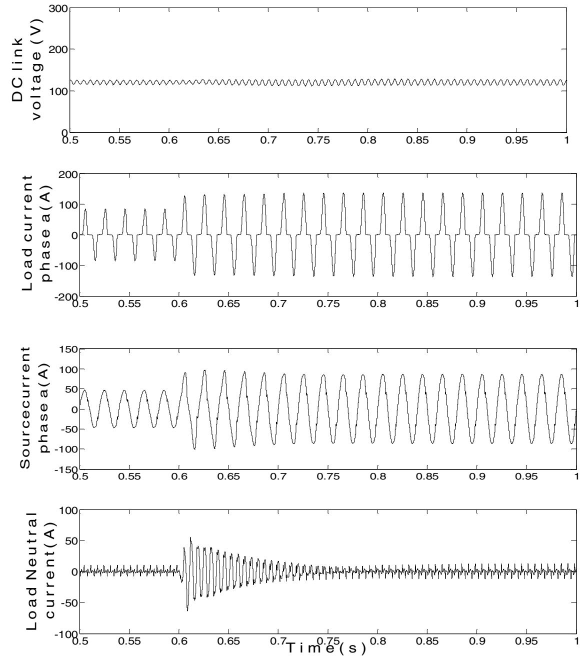

Fig. 11. Simulation results under the transient response of step-on load

at 120 V. Fig. 10 shows the simulation results of the reactive power demanded by both source and load sides. It can be seen from Fig. 10 that the reactive power is almost completely compensated by passive filters.

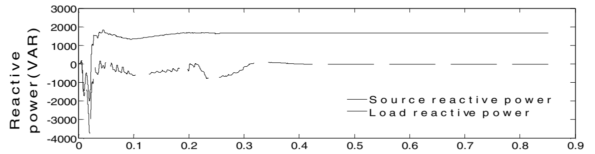

Fig. 10. Simulation results of source and load reactive power

Fig. 11 shows the simulation results of the proposed hybrid active filter using the proposed power converter under the transient response of step-on load. As seen in Fig. 11, the DC link voltage will fluctuate very low under the transient. This verifies that the hybrid active filter using the proposed power converter can be self supporting for the DC link voltage after a short transient duration.

6. Conclusions

In this paper a new three-phase four-wire hybrid active filter is proposed. The main feature of its structure is that it uses a single capacitor at DC link and neutral wire is connected directly to the positive terminal of DC link and thus avoiding split capacitors. On the other hand it saves two power switches and solves the problems of conventional structures. The proposed structure uses an LC tuned coupling circuit, which blocks the source voltage thus reducing the DC link voltage and consequently active power filter rating. A simple control method based on damping resistor is used to control the proposed hybrid active filter. Matlab/Simulink results show the capability of the proposed three-phase four-wire hybrid active filter to compensate for harmonic currents, reactive power and neutral wire current cancellation.

7. References

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