SOLUTION CONCEPT OF MODULAR SINGLE PHASE ACTIVE POWER FILTERS

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Summary This paper investigates a modular or a decentralised single-phase active power filter control strategy. It is based on the evaluation of the harmonic reference load currents for the active power filter blocks operating under specific harmonic frequencies. The underlying principle of the modular active power filter is explained and it is shown how the required reference harmonic currents can be evaluated. Simulation results demonstrated the improvement in the dynamic performance of the modular active power filter presented here in comparison with the conventional type.

1. INTRODUCTION

Electrical power systems loads usually include non-linear loads such as solid state power converters. These converters normally operate in the switching mode. Therefore, they result in the generation of higher harmonic current in the electrical power transmission system. It can cause considerable losses and voltage distortion, electromagnetic equipment failure and electromagnetic interference to neighbourhood appliances and inefficient use of electric energy. In addition, reactive currents are drawn from the ac mains due to the reactive nature of the non-linear loads. These reactive currents lead to low power factor operation of the electric power system.

Passive filters are traditionally used to filter out the voltage and current harmonics in the power systems. Normally, they can not compensate for the low power factor. In addition, they are inefficient because the switching frequency of the non-linear load power converters varies and can reach high values. Moreover, the passive filters are bulky and expensive.

Active power filters represent more effective solution to the power system quality issue. Their goal is to improve both of the harmonic distortion and the power factor of the current drawn from the ac mains at a fraction of the cost of the passive filters.

An active power filter basically consists of a power electronic converter and a source of electric energy. The latter represents the active part of the filter. It enables the filter to provide any variations of the switching frequency of the converter.

Modular active filters are capable of filtering out the voltages and currents of higher harmonics at the vicinity of their generation. Hence, it ensures that these harmonics are not transmitted throughout the distribution electrical power system. However, the active power filters can not eliminate the higher switching frequency harmonics caused by the power electronic converter constituting these filters. The switching frequency is kept constant and therefore, these harmonics can be removed by using specially designed passive filter.

Since active power filters compensate for both of the reactive and harmonic current components in the electric power systems, they give rise to considerable energy and cost savings.

Active power filters which has been reported [1], [3], compensate for the power factor and for the lower current harmonics only (up to the 5th order). This is largely due to the limitation of the computational capacity of the microcomputers used to implement the control strategies necessary for these filters and due to the maximum amount of switching losses that the power electronic devices used in the power converters comprising the filters can cope with.

Modular active power filters reported in the present work are based on the separate computation and implementation of the control strategies to evaluate the reference currents for individual modules of the modular filter. These modules operate at the fraction of the rating of the modular filter, compensate for a specific harmonic frequency and carry their own individual computational facilities. Therefore, modular active power filters are capable of compensating higher order harmonic currents than the singular structure ones. Additional advantages of these modular filters are enhanced reliability and increased operation efficiency. The first is due to the fact that the failures of one module in these filters will neither adversely affect the operation of the modular filter nor will it bring to a complete halt. The other is due to the smaller switching loss of each module in the filter because of the reduced power-handling requirement of each module. This leads to a reduction in the total switching loss in the modular filter in comparison to the singular one. One additional advantage of the modular filters is their improved transient response in comparison to singular filters. Obviously, this improvement is highly dependent on the selected control strategy to evaluate the required harmonic reference currents.

The block diagram of a modular active power filter is shown in Fig. 1. SVC (Static Var Compensator) generates the reactive reference current component. APF3 (active power factor module for the third harmonic) generates the third harmonic of the reference load current. APF5 (active power factor module for the fifth harmonic) generates the fifth harmonic of the reference load current. The modules APF7, APF9, etc., generate the other higher harmonics of the reference load current. Each of these modules comprises a power converter (usually built of IGBT solid state devices), a harmonic analyser and a passive low pass filter. The harmonic analyser contain mainly an analog to digital converter, a digital to analog converter and a digital signal processor to carry out the necessary computations to evaluate the harmonic reference current. The low pass filter compensates the switching frequency signal caused by the switching action of the power converter.

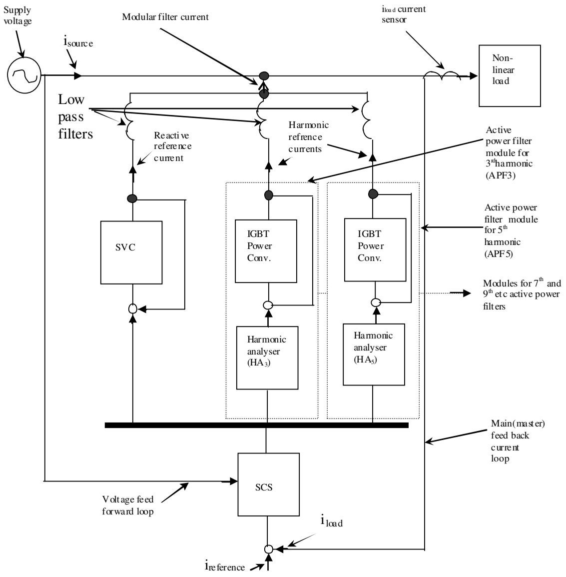

Fig. 1. Block diagram of a modular active power filter

It is obvious that the modular active power filter consists of a number of modules of active power filters where each module is tuned to generate a specific frequency of the reference harmonic current.

The SCS (Supervisory Control System) oversees the operation of all above mentioned modules and takes appropriate action to compensate the failure of any module.

2. PRINCIPLE OF OPERATION

Fig. 2 illustrates the control strategy adapted for the modular active power filter of Fig. 1. There are two levels of control systems. The algorithms in these control systems are executed simultaneously with the aid of parallel computation algorithms.

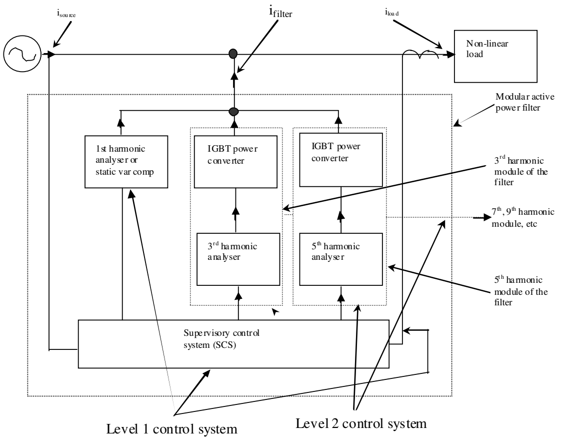

Fig. 2. Control system levels of the modular active power filter

Level 1 control system carries out the following tasks: computing the first harmonic of the load current for power factor compensation, performing the main (master) control loop algorithms, and supervising the successful operation of the filter modules for higher harmonics and taking appropriate action in case of their failures.

Level 2 control system computes the higher load current harmonics (3rd, 5th, 7th, etc.) and provides local slave current loop control.

It is important to point out that both levels (1 and 2) of control systems operate synchronously.

In order to compute the fundamental and higher load current harmonics Fourier harmonic analysis is carried out in the stationary (α, β) frame of reference. This implies that in the case of the single-phase power system being under consideration, the frequency complex domain trajectory has a 4 sided symmetry shape. Whereas the three-phase supply has a 6 sided symmetry shape. The mathematical procedure for evaluation of the reference currents harmonics is explained in the next section.

3. EVALUATION OF THE REFERENCE CURRENTS HARMONICS

The orthogonal transform technique used for the three phase power system in reference [8] is modified to be suitable for the single-phase power system under consideration in this paper.

The harmonic function describing either of the power system voltage or current is complemented by its orthogonal component so as to form a complex exponential function in the complex domain:

$$\cos(\omega t) \longrightarrow \exp(j\,\omega t) = \cos(\omega t) + j\sin(\omega t). \qquad (1)$$

This approach can be extended to non-harmonic periodic functions, accordingly:

$$\sum \cos(\omega t + \varphi) \longrightarrow \sum \exp(j\,\omega t + \varphi). \qquad (2)$$

Based on the four-side symmetry of the trajectories in the complex plan, the orthogonal co-ordinates of the non-harmonic periodic voltages and currents can be generally defined by the following complex function:

$$X(j\,\omega t) = K[x_\alpha(t) + x_\beta(t) \exp(\,j\pi/2)\,]. \quad (3)$$

Thus, for K=1, the complex function (representing either a voltage or a current) can be decomposed to its α and β components in the stationary frame of reference as follows:

- for voltages:

$$u_\alpha = u\,(t) \qquad \text{and} \qquad u_\beta = u(t-T/4), \quad (4)$$

where T is the periodic time,

- for currents:

$$i_\alpha = i\,(t) \qquad \text{and} \qquad i_\beta = i(t-T/4). \quad (5)$$

It is noted that the β components in both of equations (4) and (5) are fictitious components and the used orthogonal transformation technique can be extended to any other physical quantities in the power systems.

The fictitious β components are used to facilitate the computation of the reactive and harmonic current components in a single-phase power system as it is explained below.

The complex Fourier coefficients for the n^{th} harmonic of a non-harmonic, periodic quantity, x (t) can be evaluated as follows:

$$C_n = \frac{4}{T}\int_0^{\frac{T}{4}} x(t)\, e^{-jn\omega t}\, dt. \quad (6)$$

Using equation (3) for K=1, its possible to calculate the α and β components of C_n, thus:

$$C_{n\alpha} = \frac{4}{T}\int_0^{T} (x_\alpha(t) \cos(n\omega t) + x_\beta(t) \sin(n\omega t))\, dt, \quad (7)$$

$$C_{n\beta} = \frac{4}{T}\int_0^{T} (x_\beta(t) \cos(n\omega t) - x_\alpha(t) \sin(n\omega t))\, dt. \quad (8)$$

According to equations (7) and (8), the magnitude and phase shift of an n^{th} harmonic component of any non-harmonic periodic quantity x (t) can be evaluated as follows:

$$C_n = (C^2_{n\alpha} + C^2_{n\beta})^{1/2} \text{ and } \varphi_n = \arctan(C_{n\alpha}/C_{n\beta}). \quad (9)$$

Thus, ignoring the fictitious component, n^{th} harmonic of x (t) can be computed as follows:

$$x_n(t) = C_n \cos \varphi_n \cos(n\omega t). \quad (10)$$

Equation 10 in conjunction with equations (8) and (9) are used to compute the values of the reference harmonic load currents in the harmonic analysis blocks of Fig.1 and Fig. 2.

4. SIMULATION RESULTS

Using Matlab power block tool, simulation results for the modular active filter of Fig. 1 and Fig. 2, and for the conventional type active power filter of reference [4], [5], [7], were generated. The results are simultaneously shown in Fig. 3(a) and Fig. 3(b).

As it can be seen from these figures, for the modular filter discussed in this paper, the power system source current reaches, starting from the shown dotted line, its quasi-sinusoidal time varying state after the elapse of approximately the quarter of the periodic time of the load current. While for the conventional active power filter it takes the source current about one period to reach its steady state. Thus, the modular filter has improved dynamic performance compared to the conventional active power filter.

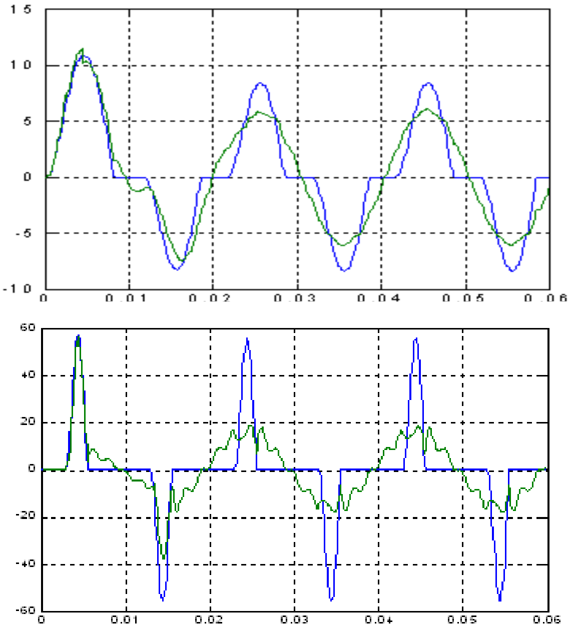

Fig. 3. Current transients under distributed control using parallel computation algorithms a) and under classical control b)

It is important to mention that the solid state power devices that are available nowadays and which are used in the power converters comprising the active power filters can carry currents of very high capacities. This implies that the improved dynamic feature of the modular filter described here might not seem to be of a major significance. However, the transient voltages induced across these devices, due to the parasitic inductances of the power supply and the transformers, is a major cause for failures of these devices. Hence, the proposed modular filter in this paper offers a solution to overcome this problem.

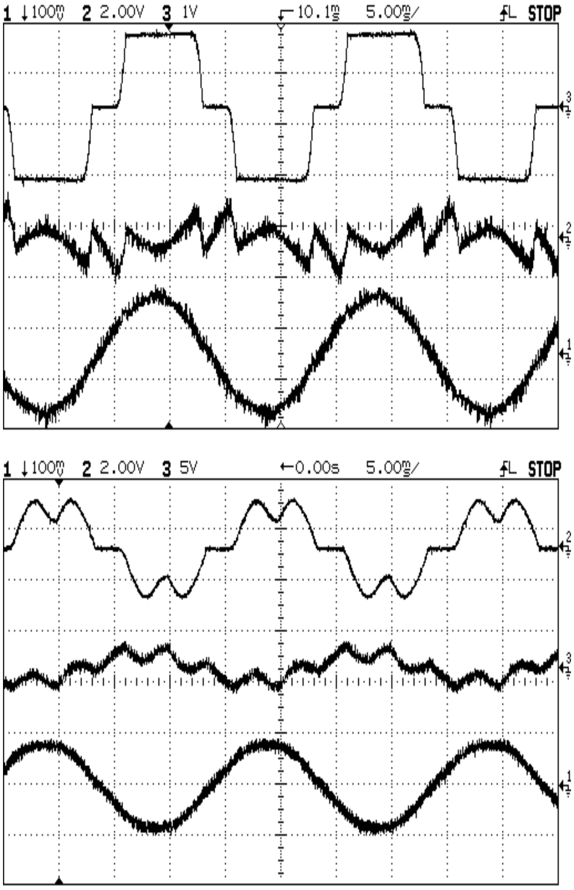

Fig. 4. Experimental results under distributed control using parallel computation algorithms with RL load a) and with RC load b)

Experimental verification of the simulation results for the modular active power filter are shown in Fig. 4(a) and Fig. 4(b). Computations of the reactive and reference currents and the necessary control algorithms would be carried out using of the Texas instruments, TMS320C31 floating point DSP.

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