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Pre-sampled data based prediction control for active power filters

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ABSTRACT

A prediction control based on pre-sampled data from previous fundamental cycle for active power filters is presented in this paper. In which the reference current is calculated by the predicted current values in few steps ahead. In this way the active filter current phase delay can be effectively compensated. In addition the detection of harmonic components of load current, design of conventional proportional–integral (PI) current controller and hardware implementation for active filters are also discussed. The proposed prediction method is simple and easy for practical application. Tests were carried out for active filter with and without the phase delay compensation. Results show that the proposed prediction method is effective in compensation the phase delay of filter current.

1. Introduction

The current harmonics caused by non-linear loads can cause voltage distortion over power distribution network as well as other undesirable phenomena, which could result in reduction in power quality [1,2]. As the harmonic current content varies with changes of operating conditions of utility network, conventional passive filters are not efficient for elimination of harmonics [3]. On the contrary, active filters in applications have been proved the most effective solution to eliminate harmonic pollution in power systems compared with conventional passive filters, an active power filter has the advantages of good controllability, fast response and high control accuracy and has now been widely applied in power systems [4].

Fig. 1 shows a typical configuration of shunt active power filters. It consists of three parts: a voltage source inverter based active filter, utility supply and the connected non-linear load.

In a active filter, the harmonic components of load current are used to constitute the reference current of current controller that controls the active filter to inject appropriate current to grid to compensation the harmonics at the point of common connection (PCC) (see Fig. 1). The detection of harmonic components of load current is, therefore, vital for an active filter to compensate the harmonics of load current accurately. There are many existing methods of detecting load current harmonics such as band-pass filter and low-pass filter based analogue method [5], Fourier transform based method [6], fuzz control based method [7], adaptive control based method [8], the instantaneous reactive power theory (IRPT) based methods [9–11], and the synchronous reference frame (SRF) based methods (I_d–I_q method) [12,13]. Among these various strategies, the IRPT and SRF based methods have been widely applied in active filters.

In this paper, an SRF method based active filter control is first discussed. The discussion includes extraction of harmonics of load current and PI current controller design. Based on the SRF method, the reference current of active filter is predicted using pre-sampled data in previous fundamental supply cycle. Comparison of results with or without predicted reference current is illustrated in the paper. Details of detection of harmonic currents, design of PI current controller, the prediction of reference current and the test results as well as discussion will be described throughout the paper.

2. Control algorithm of the active filter

For the active filter shown in Fig. 1, the basic functional diagram of its control system is shown in Fig. 2. It consists of four parts in terms of their functions: (1) phase locked loop (PLL), (2) detection of harmonics of load current, (3) *DC* link voltage regulation, and (4) PI current controller based filter current control.

2.1. PLL

The PLL detects the fundamental frequency of utility system from the supply voltages measured at PCC and locks the phase angle $\cos\omega t$ with the supply voltage vector. The load currents in stationary a–b–c reference frame are then transformed to a synchronously rotating d–q reference frame. Units vectors $\cos\omega t$ and

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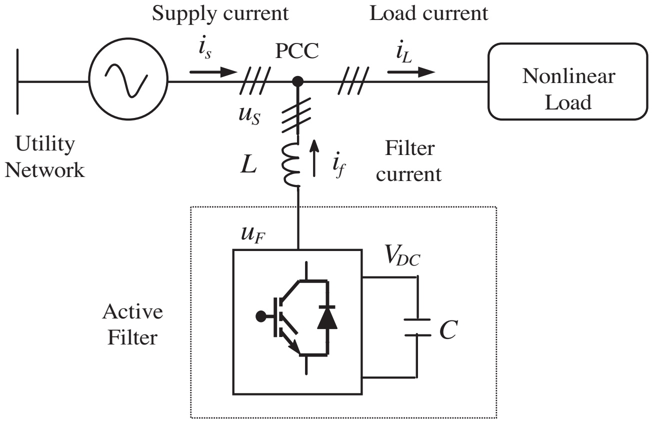

Fig. 1. Configuration of shunt active filter.

$\sin\omega t$ can be derived from the detected system frequency ω by the phase locked loop.

2.2. Detection of harmonics of load current

In the synchronous *d–q* reference frame rotating at system frequency, the positive components at the fundamental frequency are transformed to *dc* quantities while all the harmonics and the negative sequence components are transformed to non-*dc* quantities and undergo a frequency shift in the spectrum. The integrators in *d–q* rotating frame are used to extract these *dc* quantities. If the synchronous *d–q* reference frame is controlled to keep *d* axis in phase with the voltage vector, the *dc* component of the load current, I_{Ld}, in *d–q* reference frame represents fundamental active current, and I_{Lq} represents fundamental reactive current. Since any non-*dc* components in the synchronous *d–q* reference frame contribute to harmonics, the harmonic components of load current, i_{Ldh} and i_{Lqh} can be derived by subtracting *dc* components I_{Ld} and I_{Lq} from i_{Ld} and i_{Lq} respectively, as described by following equations, if the system is balanced:

$$\begin{aligned} i_{dh} &= i_{Ld} - I_{Ld} \\ i_{qh} &= i_{Lq} - I_{Lq} \end{aligned} \tag{1}$$

The harmonic components are used to constitute the reference currents of the current controller.

The *dc* components I_{Ld} and I_{Lq} are actually the averaged values of the two-axis currents in rotating *d–q* reference frame. In digital implementation, they can be calculated approximately by accumulating all sampled data in any fundamental period *T* and then dividing by the number of data samples accumulated, as described by:

$$\begin{aligned} I_{Ld}(k) &= \frac{1}{N}\sum_{n=k-N}^{k} i_{Ld}(n) \\ I_{Lq}(k) &= \frac{1}{N}\sum_{n=k-N}^{k} i_{Lq}(n) \end{aligned} \tag{2}$$

where *N* is the number of data being accumulated in one period of supply system. Index *k* represents the present sample. The i_{Ld}, i_{Lq} are the samples of load currents in *d–q* frame. For real time processing, a shifting window is employed. The width of the window is a fundamental period *T*. The window keeps shifting as the new data is sampled so the average value can be refreshed every time. This method is described by following equation, which is derived from Eq. (2):

$$\begin{aligned} I_{Ld}(k) &= I_{Ld}(k-1) + \frac{1}{N} i_{Ld}(k) - \frac{1}{N} i_{Ld}(k-N) \\ I_{Lq}(k) &= I_{Lq}(k-1) + \frac{1}{N} i_{Lq}(k) - \frac{1}{N} i_{Lq}(k-N) \end{aligned} \tag{3}$$

where $I_{Ld}(k-1)$ and $I_{Lq}(k-1)$ are the averaged values from the previous window; $i_{Ld}(k)$ and $i_{Lq}(k)$ are the latest averaged values. The window shifts one step to follow the new data so the $i_{Ld}(k-N)$ and $i_{Lq}(k-N)$ are the data being phased out from the present window. For a PWM switching frequency of 12.8 kHz (the switching frequency used in this paper) there are 256 sample points per fundamental cycle of 50 Hz system. In order to simplify the calculation, in this paper for every eight sample points, only one data is used for the calculation of average values. Therefore there are 32 points per fundamental cycle are used for calculating the average value, i.e., $N = 32$. As the number of sample points, *N*, used in the calculation is fixed the accuracy could be affected in the case of system frequency being not stable.

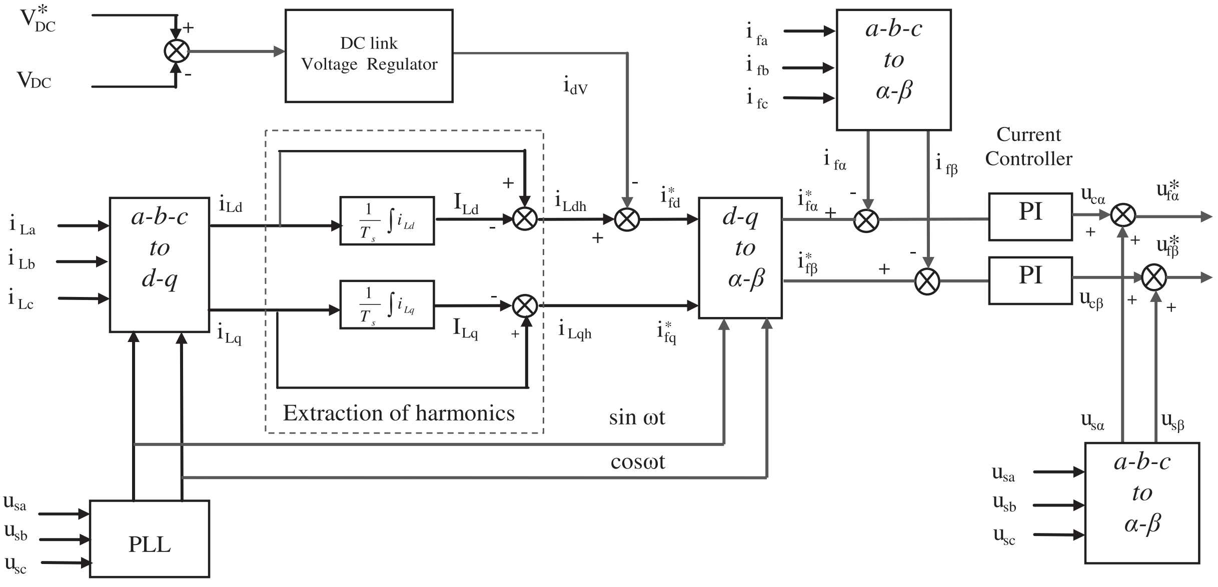

Fig. 2. Functional diagram of active filter controller.