Hysteresis Current Control of the Single - Phase Active Filter

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Abstract - To compensate harmonic current components in case of unbalanced three-phase loads authors will propose a structure composed by three single phase active filters. To begin is implemented the single-phase active filter which will be included in the structure of three-phase active filter for harmonic compensation of unbalanced consumers. Using hysteresis control technique can achieve instant control between two limits, which impose offset signal to follow the estimated reference signal with some deviation estimated by choosing the loop bandwidth. The proposed scheme is implemented with hysteresis current controller with fixed band. To obtain a compensated current with a current ripple as low as possible, the value of hysteresis band should be small. This will lead to high switching frequencies and increasing the switching losses. Advantages of using hysteresis current control are excellent dynamic performance and the ability to control the amount of peak to peak ripple current in specified hysteresis bandwidth. To estimate the reference current the Instantaneous Reactive Power Extension Theorem was used because this theorem is suitable for single - phase active filter control. For testing the command and control strategy was used a single - phase voltage source inverter (full bridge). Using Matlab / Simulink was simulating the active filter model. After connecting of active filter, in point of common coupling, voltage source and current drawn from power supply have sinusoidal variation, are in phase and voltage and current total harmonic distortion is lower than permissible level of disturbances.

Keywords - hysteresis current control, active filter, voltage source inverter

I. INTRODUCTION

Power quality is a responsibility for both the electricity supplier provider and its consumer. In most cases, the consumer of electricity is responsible for altering the power quality in the point of common coupling (PCC). Regarding power quality issues, harmonics has a significant weight, because much of the industrial consumers (over 60% of installed power at industrial consumers) contain non-linear loads, electric motor and static power converter systems [2], [12], [13]. One of the harmonics mitigation methods is to use active filter, which have a static frequency converter component. So, the use of static converters in variable speed drives, on the one hand leads to harmonics, but on the other hand these devices are used to harmonics mitigation.

Power static converters, used to the active systems for harmonics mitigation [14], [16], can be current source inverter or voltage source inverter. The last type of structure is the most commonly used in practical applications.

II. STRATEGIES FOR COMMAND AND CONTROL

The aim of active filters control is to generate signals for switching power devices in accordance with the estimated reference signal. Active filter performances are significantly influenced by the choice of control techniques. For active filter applications can specify a variety of control techniques: linear control [9], the hysteresis control [3], [6], [10], digital deadbeat control [7], [11].

Hysteresis technique assumes instantaneous control between two limits, which require the offset signal, current or voltage expected to follow the reference signal (i_uf_ref or u_f_ref) with some deviation imposed by the choice of hysteresis band width. Control scheme is illustrated by block diagram in Fig. 1.

This control technique requires a deviation H of a reference signal i_uf_ref or u_f_ref which determine the upper and lower limits of the hysteresis band. Output signals, i_f or u_f are measured and compared with its reference value (i_uf_ref or u_f_ref), the resulting error is applied to a controller with a changeover relay. This generates control signals for power switching devices, when the lower (estimated reference - H / 2) or upper (estimated value of reference + H / 2) limit are exceeded. As long as the error is in the hysteresis band, power switching devices will not be switched. Switching occurs when the error is outside the hysteresis band. Active filter is controlled so that the peak to peak value of the compensation signal, current or voltage is limited to specified hysteresis band H.

The proposed scheme is implemented with hysteresis current controller with fixed band H. To obtain a compensated current i_f with a current ripple as low as possible, the value of H should be small. This will lead to high switching frequencies and increasing the switching losses.

Advantages of using the hysteresis current control are excellent dynamic performance and the ability to control the peak to peak value of current ripple in the specified hysteresis band [15]. Implementation of this control technique is simple, which results from the controller structure in Fig. 4. However, the hysteresis control has several unsatisfactory features. The main disadvantage is that results in a variable switching frequency.

Fig. 1. Block diagram of hysteresis control technique: RBH-changeover hysteresis relay.
On the other hand, irregular switching may affect the efficiency and reliability of active filter.

III. REFERENCE CURRENT ESTIMATION

In case of the active systems for harmonic compensation, the shunt active filter, made with a voltage source inverter, the solution currently meets most of the advantages and has the fewest disadvantages. Considering the block diagram, shown in Fig. 2, we can write the relation between the currents in PCC:

\[ i_s = i_L - i_f = i_{L,A} + i_{L,h} - i_{L,h} = i_{L,1} \]  

where \( i_{L,1} \) is the fundamental current component and harmonic current components \( i_{L,h} \) of load current.

Active filter goal is to obtain a sinusoidal current drawn from the source [17] based on (1).

Reference current estimation, can be achieved especially using harmonic analysis in frequency or time domain. If in the first case can using Fourier Transform, for harmonic analysis, in the second case can successfully using Instantaneous Reactive Power Theory, developed by Akagi [1], [4], [5], [8].

For cases, when the active filter is used in single-phase networks, e.g. in the case where energy is used and supplied by a photovoltaic panel, the reference current estimation is accomplished using the extension of instantaneous reactive power theory. Thus, in the case of nonlinear loads supplied from a single-phase grid the load input current can be expressed as:

\[ i_L(t) = \sum_{N=1}^{\infty} \sqrt{2} \cdot i_{L,N} \sin(N \cdot \omega \cdot t + \varphi_N) \]  

where \( \varphi_n \) is the phase angle of the \( N^{th} \) harmonic load current component

In normal conditions, the supply voltage is sinusoidal,

\[ u_{PCC}(t) = \sqrt{2} \cdot U_{PCC} \cdot \sin(\omega t + \varphi_U) \]  

where \( \varphi_U \) is the phase angle of supply voltage.

Therefore the instantaneous load active power [9] can be expressed with:

\[ p_L(t) = u_{PCC}(t) \cdot i_L(t) = \overline{p}_L + \overline{p}_L. \]  

and instantaneous load imaginary power has the following expression,

\[ q_L(t) = u_{PCC}^*(t) \cdot i_L(t) = \overline{q}_L + \overline{q}_L. \]  

\( \overline{p}_L, \overline{q}_L \) are the DC components, \( \overline{p}_L, \overline{q}_L \) are the AC components, and \( u_{PCC}(t) \) is the supply voltage in PCC delayed by \( 90^\circ \),

\[ u_{PCC}(t) = \sqrt{2} \cdot U_{PCC} \cdot \sin(\omega t + \varphi_U - 90^\circ). \]  

Substituting (2) and (3) in (4) can write the AC and DC components of instantaneous active power:

\[ \overline{p}_L = U_{PCC} \cdot i_{L,1} \cdot \cos(\varphi_U - \varphi) - U_{PCC} \cdot i_{L,1} \cdot \cos(2 \cdot \omega \cdot t + \varphi_U + \varphi) \]  

\[ -U_{PCC} \cdot i_{L,1} \cdot \cos(2 \cdot \omega \cdot t + \varphi_U + \varphi) \]  

\[ p_L = \sum_{N=2}^{\infty} 2 \cdot U_{PCC} \cdot i_{L,N} \cdot \sin(\omega \cdot t + \varphi_U) \cdot \sin(N \cdot \omega \cdot t + \varphi_N) \]  

Substituting (2) and (6) in (5) can write expression of DC and AC components of instantaneous load imaginary power,

\[ \overline{q}_L = U_{PCC} \cdot i_{L,1} \cdot \sin(\varphi_U - \varphi) - U_{PCC} \cdot i_{L,1} \cdot \sin(2 \cdot \omega \cdot t + \varphi_U + \varphi) \]  

\[ -U_{PCC} \cdot i_{L,1} \cdot \sin(2 \cdot \omega \cdot t + \varphi_U + \varphi) \]  

\[ q_L = \sum_{N=2}^{\infty} 2 \cdot U_{PCC} \cdot i_{L,N} \cdot \sin(\omega \cdot t + \varphi_U) \cdot \sin(N \cdot \omega \cdot t + \varphi_N) \]  

Load current components, active \( i_{L,p} \), imaginary \( i_{L,q} \) and harmonic \( i_{L,h} \), are calculated by

\[ i_{L,p}(t) = \sqrt{2} \cdot \frac{\overline{p}_L}{U_{PCC}} \cdot \sin(\omega \cdot t) \]  

\[ i_{L,q}(t) = \sqrt{2} \cdot \frac{\overline{q}_L}{U_{PCC}} \cdot \sin(\omega \cdot t - 90^\circ) \]  

\[ i_{L,h}(t) = i_L(t) - i_{L,p}(t) - i_{L,q}(t) \]  

Compensation current reference is expressed with following relation:

\[ i_{f,ref} = i_{L,q} + i_{L,h} - I_{C2} \cdot \sin(\omega \cdot t) \]  

where \( I_{C2} \) is the RMS value of the capacitor charging current, from DC bus voltage of the voltage source inverter.

IV. ACTIVE FILTER MODEL AND SIMULATION

The active filter model is implemented using the software Matlab \ Simulink. Fig. 3 shows the block diagram of model, and consists of: power supply, nonlinear load, active filter command and control, signals acquisition and signals measurements.

A. Block “Active Filter”

“Active filter” block is represented in Fig. 4 and consist in a voltage source inverter, a coupling coil L3 and a capacitor C2, in DC bus circuit.
DC bus reference voltage $U_{C2}$ used for simulation is set to the value of 350 V, a value of about 1.5 times higher than the power supply voltage. The maximum values of frequency switching ripple, $f_{sw,max}$, and peak to peak ripple, $\Delta I_{sw,p-p}$, of switching current generated by the inverter are selected to be 10 kHz and 1 A. The minimum value of inductance $L3$ can be determined as 17 mH and for capacity $C2$ of 4700 μF.

B. Active Filter Command and Control Block

At the output of control block (Fig. 5) it should generate control signals for power electronic devices. It consists of four blocks as follows: “Reference sine generator”, “Reference current estimation”, “DC bus voltage regulator” and “Hysteresis current control”.

C. Reference Sine Generator Block

On output, the block (Fig. 6) generates two sinusoidal signals with equal amplitude and in phase with the supply voltage at PCC. To remove high frequency noise and zero crossing frequency higher than the fundamental was used a second order discrete low pass filter with cutoff frequency set at 100 Hz.

D. Reference Current Estimation Block

The input signals, power supply voltage in PCC and current drawn by the load is filtered to remove noises with discrete filters (Fig. 7). Their cut-off frequency is set to 2 kHz.

E. Hysteresis Current Control Block

Hysteresis control technique requires instant control based on changeover relay (Fig. 8), which forces the estimated compensation reference current to follow the reference current. Resulting error is applied to changeover relay to generate control signals for power switching devices. As long as the error is in the imposed hysteresis bandwidth of the loop the output active filter current may increase or decrease depending on the previous state of power devices, blocked or in conduction. When the difference reaches selected hysteresis thresholds the power devices, which was in conduction, are turned-off, and others two, which was blocked, are in conduction.
For model simulation the hysteresis bandwidth is set to a value of 1 A.

V. ACTIVE FILTER SIMULATION

Waveform of voltage supply in PCC is shown in Fig 9. This have a sine variation with a THD about 0.1 %, and the RMS value of the voltage is 229.9 V.

The waveform of the current drawn by non-linear loads in the absence of active filter is shown in Fig. 10. Harmonic analysis put in evidence distortion of the current waveform, with THD about of 84.87%, and the RMS value of the current is 20.83 A.

At the output of “Reference sine generator” block waveforms obtained are shown in Fig. 11. It is noted that the reference sine waveforms have amplitude equal to unity and $\sin(\omega t)$ is in phase with the source voltage, and $\sin(\omega t-90^\circ)$ lags with $90^\circ$.

“Reference current estimation” block generate the estimated reference current used for harmonic compensation (Fig. 12). Fig. 13 presents the waveforms of active and reactive current components. These have sine variations and phase shifted with $90^\circ$.

Hysteresis current control of the active filter means to generate appropriate control signals for the power devices so that the current output from the active filter to follow the estimated current reference (Fig. 14).
lent dynamic performance and the ability to control the deviation estimated by choosing the loop bandwidth. Advantages of using hysteresis current control are excellent current to follow the estimated reference current with simple control between two limits, which impose the generation of switching ripple and are in phase. Harmonic analysis shows in Figs. 15 and 16.


