A Novel Control Algorithm for an Adaptive Hysteresis Band Current Controlled Shunt Active Power Filter

T Raju¹, P Ram Reddy²
¹,²(Electrical & Electronics Engineering, Kamala Institute of Technology & Science, Singapur, Andhrapradesh, India.)

Abstract- This paper presents a single phase shunt Active Power Filter (APF) for harmonic and reactive power compensation. A simple method, using Fourier series block has been proposed for APF reference current generation. This method simplifies the calculation algorithm. A high performance adaptive hysteresis band current controller tracks the reference current. It changes the hysteresis bandwidth according to the modulation frequency, supply voltage, DC bus voltage and slope of reference current. MATLAB / SIMULINK model has been presented. Responses of the simulated model show that harmonic and reactive components of load current are completely eliminated from supply current.

Index Terms- active power filter, adaptive hysteresis band current controller, reference current generation, voltage source inverter.

I. INTRODUCTION

Increasing usage of non-linear loads are resulting in barely acceptable power supply quality because of largeharmonic distortions in current and voltage. The harmonics generated by non-linear loads have several detrimental effects on various power system components. The harmonic currents give rise to voltage drop at their respective harmonic frequencies distorting the PCC (Point Of Common Coupling) voltage which may also cause resonance problems. Modern active power filters (APFs) serves as a solution to this problem with multiple functions; harmonic filtering, reactive power compensation, voltage-flicker reduction, load balancing and/or their combinations.

APFs, may be classified into pure active filters and hybrid active filters[2][3]. Hybrid APFs are primarily used for harmonic mitigation. Fast switching low power loss power electronic devices and fast digital signal processing devices available at an affordable cost, it is feasible to embed a variety of functions into a pure APF to make it a power quality conditioner.

APFs are current controlled, voltage source inverters (VSI) which are intended to inject a compensating current into the system to relieve the supply from harmonic and reactive currents and enhance power quality indices. There are two major parts of an APF. The first one is the controller that determines the compensating current to be injected at PCC and the necessary active component of the current to be absorbed, required to maintain the D.C. bus voltage. Various compensating current calculation techniques are discussed in [4]. In this paper, a simple technique based on Fourier analysis has been presented. Secondly, there is a current controlled VSI. As the load harmonics may be complex, change rapidly and randomly, APF has to respond quickly with high control accuracy in current tracking. To ensure security and efficiency of APF operation, the switching frequency of VSI, the D.C. bus voltage should be as minimum as possible. Among the available methods[6][8], Hysteresis Band Current Control method is characterized by its ease of implementation with high accuracy and quick response. Use of conventional hysteresis band current control is limited due to wide variations in switching frequency and its associated effects. In this paper, an adaptive hysteresis band current controller [10] has been implemented which ensures least variation in device switching frequency by maintaining the merits of the basic technique.

II. GENERAL DESCRIPTION OF THE SYSTEM
Fig 1: General Block diagramhaving

The single phase supply system shown in Fig. 1, is connected to a non-linear load, taking current \( i_L(t) \), and the figure shows significant harmonics and reactive power. Based upon Fourier analysis, reference current calculator will extract the reactive and harmonic current component of the load current and generate the compensating current \( c(t) \). Depending upon error \( (V_{dref} - V_d) \), PI controller will determine the necessary active component of current \( (isc) \) to be absorbed by APF from supply in order to maintain D.C. bus voltage. Phase Locked Loop (PLL) is used to generate a sinusoidal reference locked to the fundamental component of supply voltage used to determine the instantaneous current \( isc(t) \). PLL output is also used to trigger the sampling and integration block. The resultant reference current, \( iref*(t) \), will be given as a command current to the current controller. The current controller consists of adaptive hysteresis band (HB) calculator. It will calculate HB to maintain constant switching frequency, \( f_A \). HB can be varied as a function of \( iref*(t)-dt \) and \( V_{dc} \) to maintain \( f_A \). The hysteresis current controller tracks the reference current \( iref*(t) \) by generating device switching signals to control amplification of current, \( ia(t) \), in the coupling inductor \( L \), within hysteresis band, HB.

### III. REFERENCE CURRENT CALCULATOR

Methods based on the instantaneous power theory [2][8] have been used in three phase APFs. The instantaneous power theories are not directly applicable to single phase system. Many methods of single phase applications are given in [4]. The method used here is the desired mains current is hence assumed to be the product of the magnitude of the real component of fundamental load current \( (I_1, \cos \phi) \) and a unity sinusoidal wave in phase with the mains voltage. An unity sinusoidal reference is generated by using the PLL. Subtracting this fundamental active current from the load current gives the exact harmonic and reactive current component that should be supplied by the APF by injecting the compensating current at PCC.

\[
i_L(t) = \sum_{n=1}^{N} I_{Ln} \sin(n\omega t + \phi_n) - - - - - - - (1)
\]

\[
i_L(t) = I_{L1} \cos(\phi_1) \sin(\omega t) + I_{L1} \sin(\phi_1) \cos(\omega t) + \sum_{n=2}^{N} I_{Ln} \sin(n\omega t + \phi_n) - - - (2)
\]

\( \omega \) -- \( \text{fundamental angular frequency} \)

\( I_{Ln} \) and \( \phi_n \) are the peak value and phase angle of the nth harmonic current respectively.

\( i_L(t) \) can be divided into three components,

\[
I_L(t) = I_{L1p}(t) + I_{L1q}(t) + I_{L1h}(t)
\]

\( I_{L1p}(t) \) is active fundamental component,

\[
I_{L1p}(t) = I_{L1} \cos(\phi_1) \sin(\omega t) - - - (3)
\]

\( I_{L1q}(t) \) is reactive fundamental component,

\[
I_{L1q}(t) = I_{L1} \sin(\phi_1) \cos(\omega t) - - - (4)
\]

\( I_{L1h}(t) \) is harmonic component,
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\[ I_{Lh}(t) = \sum_{n=2}^{N} I_{Ln} \sin(n\omega t + \phi_n) \]  

The magnitude of fundamental current \( I_{L1} \) and displacement angle \( \phi_1 \) can be determined from the simulation by using Fourier series block.

By multiplying the magnitude of fundamental current \( I_{L1} \), cosine of the displacement angle \( \phi_1 \), and the unit sinusoidal wave generated from the PLL gives the Fundamental Active component \( I_{L1p}(t) \).

Compensating current \( i_c(t) = i(t) - i_{L1p}(t) \)  

In addition to the above current, Depending upon error signal \( (V_{dcref} - V_d) \), PI controller will determine the peak value of charging current \( I_{sc} \), required to be absorbed by APF to charge the capacitor. Hence APF reference current is given by,

\[ \text{isc}(t) = I_{sc}\sin(\omega t) \]

The APF reference current \( \text{iref}(t) = i_c(t) + \text{isc}(t) \)

\[ \text{Fig 2 Simulink model for reference current generator} \]

IV. ADAPTIVE HYSTERESIS BAND CALCULATOR

Adaptive hysteresis band calculator varies the hysteresis band width, HB, according to \( \text{diref}^*(t)/dt \) and \( V_{dc} \) and supply voltage \( V_s \). The analytical derivation is given below indicates that by variation in HB, switching frequency, \( f_{sw} \), can be maintained nearly constant. When the current in the injection inductor tries to leave the hysteresis band appropriate switch is turned ON or OFF to force the ramping of the current within the hysteresis band.

\[ L \frac{di^+}{dt} = V_{dc} - V_s \]

\[ L \frac{di^-}{dt} = -(V_{dc} + V_s) \]

In the intervals \( t_1 \) and \( t_2 \) \( i_a^+ \) and \( i_a^- \) can be expressed as

Where \( L \) coupling inductance

\[ i_a^+ \text{ an} \]
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dia- are the respective rising and falling currents
fsw is the switching frequency
Adding (10) and (11) and substituting (12), we get

\[
\frac{di^+}{dt} t_1 - \frac{di^+}{dt} t_1 = 2HB \quad \ldots \ldots \ldots \ldots (10)
\]

\[
\frac{di^-}{dt} t_2 - \frac{di^-}{dt} t_2 = -2HB \quad \ldots \ldots \ldots \ldots (11)
\]

\[
t_1 + t_2 = T_c = \frac{1}{f_{sw}} \quad \ldots \ldots \ldots \ldots (12)
\]

\[
\frac{di^+}{dt} t_1 + \frac{di^-}{dt} t_2 - \frac{1}{f_{sw}} \frac{di^+}{dt} = 0 \quad \ldots \ldots \ldots \ldots (13)
\]

Subtracting (11) from (10) and substituting (12), we get

\[
\frac{di^+}{dt} t_1 - \frac{di^-}{dt} t_2 - (t_1 - t_2) \frac{di^+}{dt} = 4HB \quad \ldots \ldots \ldots \ldots (14)
\]

Subtracting (11) from (10) and substituting (12), we get

\[
- \frac{V_{dc}}{L} \frac{t_1 - t_2}{f_{sw}} - \frac{1}{f_{sw}} \frac{V_s}{L} + \frac{di^+}{dt} = 0 \quad \ldots \ldots \ldots \ldots (15)
\]

\[
(t_1 - t_2) = \frac{L}{V_{dc} f_{sw}} \frac{V_s}{L} \frac{di^+}{dt} \quad \ldots \ldots \ldots \ldots (16)
\]

Substituting (10), (11) and (16) in (14) and simplifying

\[
HB = \frac{0.25V_{dc}}{f_{sw} L} \left[1 - \frac{L}{V_{dc}^2} \left(\frac{V_s}{L} + m\right)^2\right] \quad \ldots \ldots \ldots \ldots (17)
\]

\[m = \frac{di^+}{dt}\]

The equation (17) indicates that HB can be modulated as a function of Vdc, Vs, and m so that fsw remains constant.

Fig 4 Simulink model for adaptive hysteresis band calculator.

V. SIMULATION RESULTS AND DISCUSSIONS

The simulated system consists of a single phase source feeding nonlinear load having significant harmonic and reactive component. The system parameters are listed in Table 1
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage, Vs</td>
<td>230 V</td>
</tr>
<tr>
<td>Supply frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>DC Bus voltage, Vd,</td>
<td>450 V</td>
</tr>
<tr>
<td>Coupling Inductor, L</td>
<td>2 mH</td>
</tr>
<tr>
<td>DC side capacitor</td>
<td>5000 uF</td>
</tr>
<tr>
<td>Inductance of rectifier load</td>
<td>10 mH</td>
</tr>
<tr>
<td>Resistance of rectifier load</td>
<td>5 ohms</td>
</tr>
</tbody>
</table>

Table 1 Test Circuit parameters

Test system is simulated for 1 sec. Load is varied for every 200ms time. Results are shown from 0.1 to 0.3 sec. Wave forms of source currents, load currents, and harmonic spectrums of source and load currents are shown from Fig 5 to Fig 11. Fig 5 and Fig 6 shows load current and source current respectively. Fig 7 and Fig 8 shows inverter injecting current (actual current measured) and DC bus voltage respectively. Fig 9, Fig 10 and Fig 11 shows the harmonic spectrums of the load current, source current and switching frequency respectively. We can observe that THD on source side has reduced from 27% to 4.02%. Thus results show APF with conventional control effectively compensates both harmonic and reactive powers. The switching frequency is also maintained nearly constant and also maintaining the merits of the conventional technique.
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Fig 7 Inverter injecting current (actual current) from 0.1sec to 0.3sec

Fig 8 DC bus voltage (V)

Fig 9 Load current Harmonic Spectrum (magnitude (% of fundamental) Vs Harmonic order) Total Harmonic Distortion = 27%

Fig 10 Source current Harmonic Spectrum (magnitude (% of fundamental) Vs Harmonic order) Total Harmonic Distortion = 4.02%
VI. CONCLUSIONS

From the simulation responses, it is evident that the reference current generator and the adaptive hysteresis band current controller are performing satisfactorily. The paper describes a simple technique based on Fourier analysis (ICOS\(\phi\)) algorithm determines the peak fundamental active component of the load current. The adaptive hysteresis band calculator dynamically adjusts the hysteresis bandwidth with the objective of constant device switching frequency. The source current waveform is in phase with the utility voltage and free from harmonic components. The validation is carried out on the basis of simulation results.

REFERENCES


[8]. Suresh Kumar K.S. “Three phase shunt active power filter control strategies”

