International Refereed Journal of Engineering and Science (IRJES)
e- ISSN :2319-183X *p-ISSN :* 2319-1821
On Recent Advances in Electrical Engineering

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

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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, voltagesourceinverter.*

I. INTRODUCTION

Increasing usage of non-linear loads are resulting inbarely acceptable power supply quality because of largeharmonic distortions in current and voltage. The harmonicsgenerated by non - linear loads have several detrimental effectson various power system components. The harmoniccurrents give rise to voltage drop at their respective harmonicfrequencies distorting the PCC (Point Of Common Coupling)voltage which may also cause resonance problems. Modernactive power filters(APFs) serves as a solution to this problemwith multiple functions; harmonic filtering, reactive powercompensation, voltage-flicker reduction, load balancing and/ortheir combinations.

APFs, may be classified into pure active filters andhybrid active filters[2][3]. Hybrid APFs are primarily used forharmonic mitigation. Fast switching low power loss powerelectronic devices and fast digital signal processing devicesavailable at an affordable cost, it is feasible to embed a varietyof functions into a pure APF to make it a power qualityconditioner.

APFs are current controlled, voltage source inverters(VSI) which are intended to inject a compensating current intothe system to relieve the supply from harmonic and reactivecurrents and enhance power quality indices. There are twomajor parts of an APF. The first one is the controller thatdetermines the compensating current to be injected at PCC andthe necessary active component of the current to be absorbed,required to maintain the D.C. bus voltage. Variouscompensating current calculation techniques are discussed in [4]In this paper, a simple technique based on Fourier analysis has been presentedSecondly, there is a current controlled VSI. As the loadharmonics 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 APFoperation, the switching frequency of VSI, the D.C. bus voltageshould be as minimum as possible. Among theavailable methods[6][8], Hysteresis Band Current Control method ischaracterized by its ease of implementation with high accuracyand quick response. Use of conventional hysteresis band currentcontrol is limited due to wide variations in switching frequencyand its associated effects. In this paper, an adaptive hysteresisband current controller [10] has been implemented whichensures least variation in device switching frequency bymaintaining the merits of the basic technique.

II. GENERAL DESCRIPTION OF THE SYSTEM

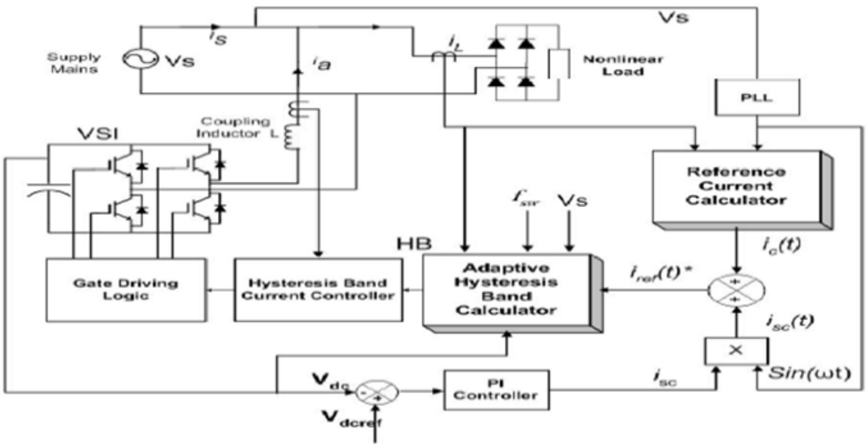

Fig 1: General Block diagramhaving

The single phase supply system shown in Fig. 1, is connected toa non-linear load, taking current $i_L(t)$, andFig 1: General Block diagramhaving significantharmonics and reactive power. Based upon Fourier analysis, reference currentcalculator will extract the reactive and harmonic currentcomponent of the load current and generate the compensatingcurrent currentic(t), Depending upon error (Vdcref - Vd), PIcontroller will determine the necessary active component ofcurrent (Isc) to be absorbed by APF from supply in order tomaintain D.C. bus voltage. Phase Locked Loop (PLL) is usedto generate a sinusoidal reference locked to the fundamentalcomponent of supply voltage used to determine theinstantaneous current isc(t). PLL output is also used to triggerthe sampling and integration block. The resultant referencecurrent, iref*(t)= (ic(t)+isc(t)), will be given as a command current to the current controller. The current controller consists of adaptive hysteresis band (HB) calculator. It will calculateHB to maintain constant switching frequency, fA. HB can be varied as a function of diref*(t)1dt and Vdc to maintain f". The hysteresis current controller tracks the reference current iref*(t)by generating device switching signals to control amping ofcurrent, ia(t), in the coupling inductor L, within hysteresisband,HB.

III. REFERENCE CURRENT CALCULATOR

Methods based on the instantaneous power theory [2][8] have been used in three phase APFs. The instantaneous power theoryis 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.cos□) 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.

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

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

ω --→fundamental angular frequency

I_{Ln} and ϕ_n are the peak value and phase angle of the nth harmonic current respectively.

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

$I_L(t) = I_{L1p}(t) + I_{L1q}(t) + I_{Lh}(t)$

$I_{L1P}(t)$ is active fundamental component,

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

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

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

$I_{Lh}(t)$ is harmonic component,

$$\mathrm{I_{Lh}}(\mathrm{t}) = \sum_{n=2}^{N} I_{Ln} \sin(n\omega t + \phi_n) - - - (5)$$

The magnitude of fundamental current I_{L1}&displacement angle $\square_1$ can be determined from the simulation by using Fourier series block.

By multiplying the magnitude of fundamental currentI_{L1}, cosine of the displacement angle $\square_1$and the unit sinusoidal wave generated from the PLL gives the Fundamental Active component $I_{L1P}(t)$.

Compensating current $ic(t)=i_L(t)-i_{L1p}(t)$ ---------(6)

In addition to the above current, Depending upon error signal (V_{dcref}- V_{dc}), 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,

$isc(t)=I_{sc}\sin(\omega t)$

The APF reference current iref(t)=ic(t)+isc(t)----(7)

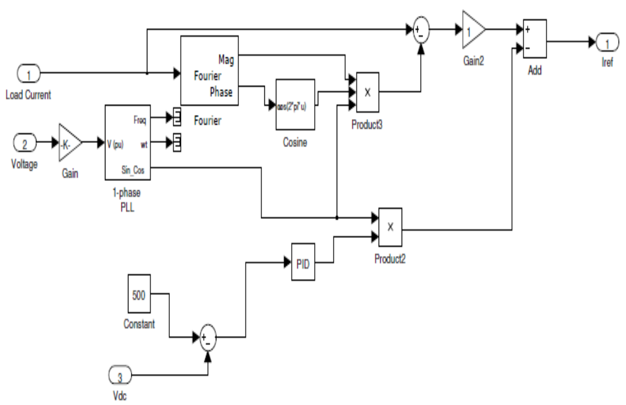

Fig 2 Simulink model for reference current generator

IV. ADAPTIVE HYSTERESIS BAND CALCULATOR

Adaptive hysteresis band calculator varies the hysteresis band width, HB, according to diref*(t)/dt and Vdc and supply voltage Vs. The analytical derivation is given below indicates that by variation in HB, switching frequency, fsw, 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.

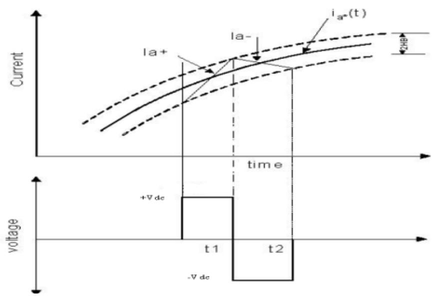

Fig 3 single phase VSI with HCC and current and voltage waveforms

$$L\frac{di^{+}}{dt} = V_{dc} - V_s \text{ - - - - - - - - - - -}(8) \quad L\frac{di^{-}}{dt} = -(V_{dc} + V_s)\text{......... ....}(9)$$

In the intervals t1 and t2 ia+ and ia- can be expressed as

Where L coupling inductance

ia+ an

d ia- are the respective rising and falling currents
fsw is the switching frequency
Adding (10) and (11) and substituting (12), we get

$$\frac{di^+}{dt} t_1 - \frac{di^*}{dt} t_1 = 2HB \text{.......... ....}(10)$$

$$\frac{di^-}{dt} t_2 - \frac{di^*}{dt} t_2 = -2HB \text{.......... ....}(11)$$

$$t_1 + t_2 = T_c = \frac{1}{f_{sw}} \text{.......... ....}(12)$$

$$\frac{di^*}{dt} t_1 + \frac{di^-}{dt} t_2 - \frac{1}{f_{sw}} \frac{di^*}{dt} = 0 \text{..................}(13)$$

$$\frac{di^+}{dt} t_1 - \frac{di^-}{dt} t_2 - (t_1 - t_2)\frac{di^*}{dt} = 4HB \text{.......... ....}(14)$$

Subtracting(11) from (10) and substituting (12), we get
substituting (8) and (9) in (14)

$$-\frac{V_{dc}}{L}(t_2 - t_1) - \frac{1}{fsw}(\frac{Vs}{L} + \frac{di^*}{dt}) = 0 \text{.......... ....}(15)$$

$$(t_2 - t_1) = -\frac{L}{V_{dc} f_{sw}}(\frac{Vs}{L} - \frac{di^*}{dt}) \text{..............................}(16)$$

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

$$HB = \frac{0.25V_{dc}}{f_{sw}L}[1 - \frac{L^2}{V_{dc}^2}(\frac{V_s}{L} + m)^2] \text{........}(17)$$

$$m = \frac{di^*}{dt}$$

where
The equation (17) indicates that HB can be modulated as a function of V_{dc}, V_s, and m so that f_{sw} remains constant.

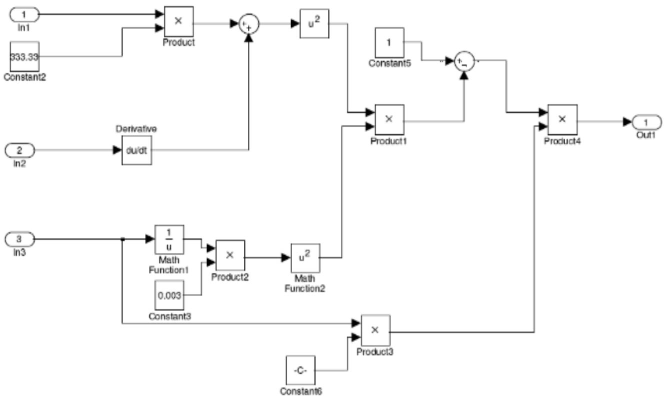

Fig 4Simulink model for adaptive hysteresis band calculator.

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

Supply Voltage, Vs	230 V
Supply frequency	50 Hz
DC Bus voltage, Vd,	450 V
Coupling Inductor, L	2 mH
DC side capacitor	5000 uF
Inductance of rectifier load	10 mH
Resistance of rectifier load	5 ohms

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.

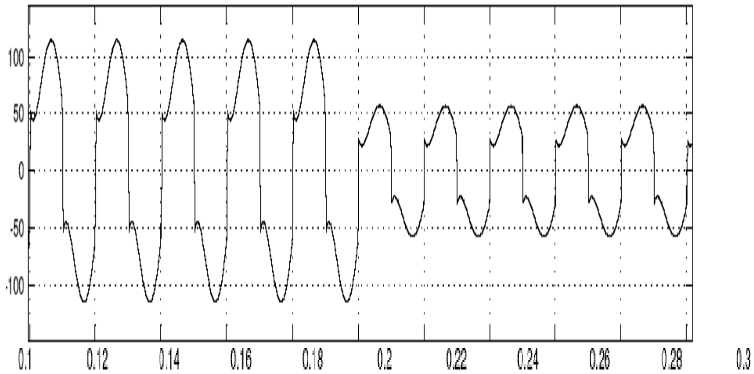

Fig 5 Load current(A) from 0.1sec to 0.3sec

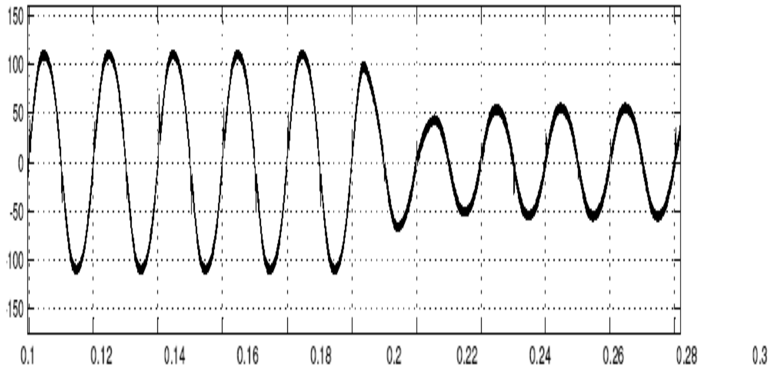

Fig 6 Source current(A) from 0.1sec to 0.3sec

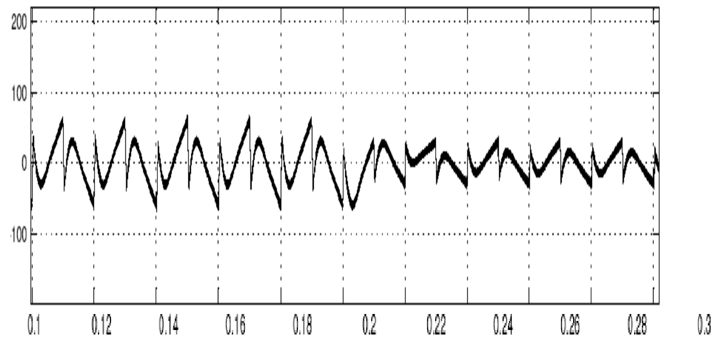

Fig 7 Inverter injecting current (actual current) from 0.1sec to 0.3sec

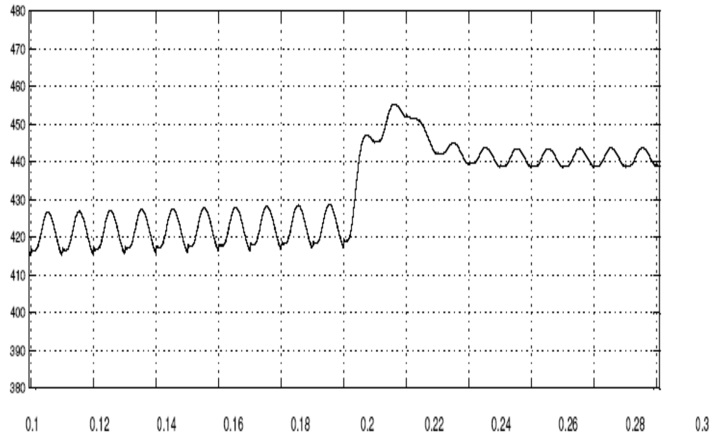

Fig 8 DC bus voltage(V)

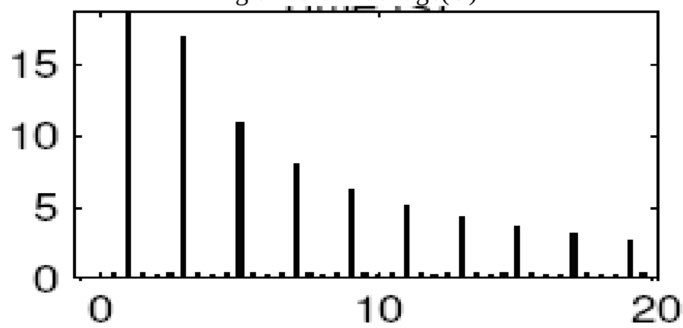

Fig 9 Load current Harmonic Spectrum (magnitude (% of fundamental) Vs Harmonic order) Total Harmonic Distortion =27%

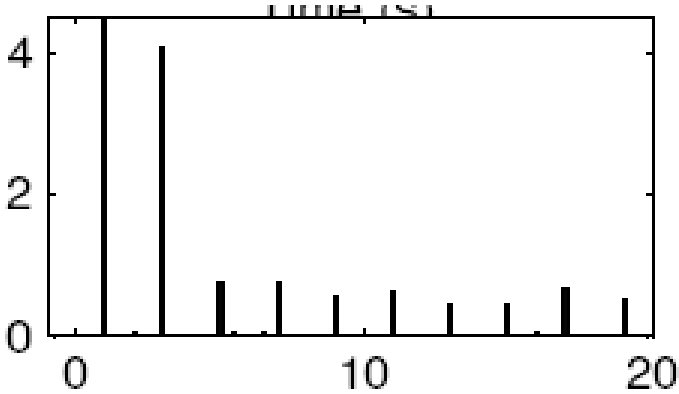

Fig 10 Source current Harmonic Spectrum (magnitude (% of fundamental) Vs Harmonic order) Total Harmonic Distortion =4.02%

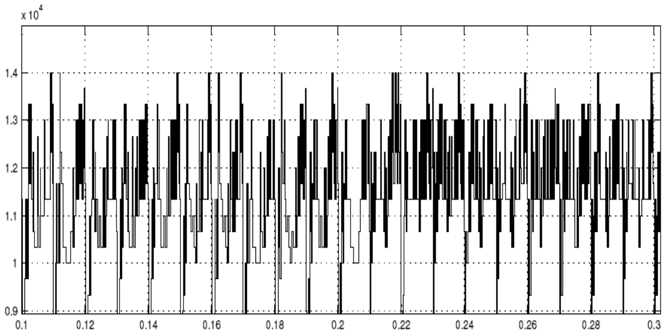

Fig 11 Switching frequency.(Hz)

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) 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.

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