A Study of Hysteresis Band Current Control Scheme For Shunt Active Power Filter Used For Harmonics Mitigation

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***Abstract*—** This paper gives an analysis of harmonic currents in power electronics equipment produced by nonlinear loads.. Shunt active power filters (APF) play a key role to reduce harmonics current generated by nonlinear loads. Impact of shunt active power filter (APF) for compensating the harmonics current has been examined and analyzed by using Hysteresis current control technique. In this paper, harmonic control strategy is applied to compensate the current harmonics in the system. A comparative study between PI, HCC, adaptive HCC for the harmonic current mitigation has been used using shunt active filter technique. Simulated results are analyzed using MATLAB

Index Terms— **Harmonic Suppression, Hysteresis Current control, PI Controller, Power System, Shunt Active Power Filter**.

INTRODUCTION

The non linear loads such as lighting with electronic ballasts, switch mode power supply, single phase SMPS, battery chargers, rectifiers, inverters, three phase power converter fed drives, arc furnaces, arc welding, discharge lighting and saturable reactors etc. will produce current harmonics in the power system leading to current and voltage waveform distortion. All these loads draw the non sinusoidal currents resulting in current harmonics and are injected back into the supply system through the point of common coupling (PCC).These power electronics loads are categorized as nonlinear loads. Over the last few years there has been a continuous increase of nonlinear type of loads due to the extensive use of power electronic conversion and control in all types of industries as well as the general consumers of electric energy.The shunt active power filter makes use of power electronic switching technology and advanced control techniques to mitigate the harmonic distortion caused by nonlinear loads. The most desirable filters are those that compensate harmonics as well as reactive power. These are more suited for low power applicationsThe quality of electric power is deteriorating mainly due to current and voltage harmonics, zero and negative sequence components, voltage sag, voltage swell, flicker, voltage interruption, etc. Shunt active filter (SAF) is one among the various types of custom power devices proposed to improve the power quality [2]. Harmonic detection methods can be classified in two domains; Frequency domain, Time domain. Frequency domain has harmonic reduction techniques like Discrete Fourier Transform, Fast Fourier Transform and Recursive Discrete Fourier Transform. In time domain d-q frame and p-q theory has been developed. The hysteresis controller in its simplest form is being developed. The current error for each phase is fed back in to a two level hysteresis comparator .The switching signals are produced directly when the error exceeds an assigned tolerance band. The advantages of this controller are simplicity, excellent robustness and independence of system parameter changes, lack of tracking errors and very good dynamics, limited only by switching speed and system time constant. In addition it is not necessary to measure the supply voltage to derive an angle, *0*, thereby reducing costs by eliminating a transducer. The paper is organized as follows. In section I basic operation of shunt active power filter section II Development of control scheme for shunt Active Filters is explained Hysteresis current control scheme used is developed in section III. Section IV outlines the MATLAB implementation and simulation results for the proposed configuration. Finally conclusion is presented in Section V. 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.

I. SHUNT ACTIVE POWER FILTER

The most important configuration widely used in active filtering applications for current harmonic reduction and power factor improvement is shunt active filters The shunt active power filter (APF) is a device that is connected in parallel to and cancels the reactive and harmonic currents from a nonlinear load. The resulting total current drawn from the ac main is sinusoidal. Ideally, the APF needs to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line. In an APF depicted in Fig. 1, a current controlled voltage source inverter is used to generate the compensating current (ic) and is injected into the utility power source grid. This cancels the harmonic components drawn by the nonlinear load and keeps the utility line current (is) sinusoidal.

One of the most popular Active Power Filters (APF) used for compensating reactive power and harmonics is the shunt active filter that is shown in figure 1. The simple shunt active filter arrangement with non-linear load is considered.

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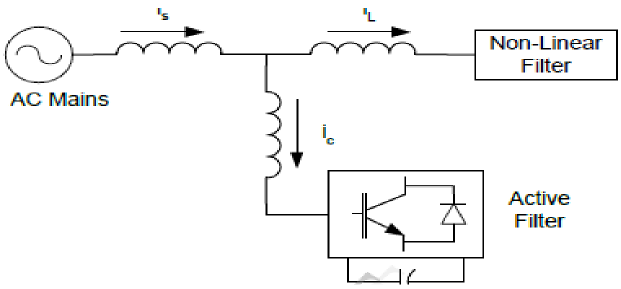

Figure1. Shunt Active Power Filter with Non linear load

The desired current waveform is obtained by accurately controlling the switching of the insulated gate bipolar transistors (IGBT's) in the inverter. Control of the current wave shape is limited by the switching frequency of the inverter and by the available driving voltage across the interfacing inductance. The driving voltage across the interfacing inductance determines the maximum di/dt that can be achieved by the filter. This is important because relatively high values of di/dt may be needed to cancel higher order harmonic components. Therefore, there is trade –off involved in sizing the interface inductor. A large inductor is better for isolation from the power system and protection from transient disturbances.

II. CONTROL TECHNIQUES FOR ACTIVE POWER FILTER

The performance of active filter is dependent on two parts: current control system and harmonic reference generation. The development of compensating signals in terms of voltages or currents is the important part of APF's control strategy which affects its ratings and transient as well as steady state performance. The control strategy which generates compensating signals is based on time-domain or frequency-domain. The frequency domain approach makes the use of the Fourier transform and its analysis, which leads to a large amount of calculations, making the control method much more complicated. In the time domain approach, traditional concepts of circuit analysis and algebraic transformations associated with changes of reference frames are used, simplifying the control task. in this section, shunt active filter system is simulated with three controllers viz, PI control scheme, Hysteresis control scheme, adaptive Hysteresis controller.. The various non linear loads considered are diode bridge rectifier, AC voltage controller load and DC Motor loads.

3.1 ANALYSIS WITH PI CONTROLLER

The control scheme of the shunt active power filter uses a voltage regulation circuit on the DC capacitor. The block diagram of the overall control scheme is shown in Fig.2The control variables used by the PI control algorithm are the DC bus voltage, supply current and supply voltage. The DC capacitor voltage has a second harmonic ripple and if used without filtering, it will appear in the compensated supply current. A low pass filter has to be used on the DC bus to eliminate this ripple which causes considerable delay in the compensation process. It is observed that the capacitor voltage remains constant at all zero crossings. This circuit make use of sample and hold . The error in the PI controller and the amplitude of supply current provided by the controller are thus made available at zero crossing only and the supply current is maintained constant for the entire period of one cycle. The ripple in the capacitor is eliminated with this technique and there is no need to use the low pass filter. PI controller [6] drives the system to be controlled with a weighted sum of the error and the integral of that value . It has simple arithmetic and high reliability in steady state . It does not require any transformation and it simplifies the controller design. The simulation of shunt active filter for an uncontrolled diode bridge rectifier with RC load using PI controller is shown in fig. 2

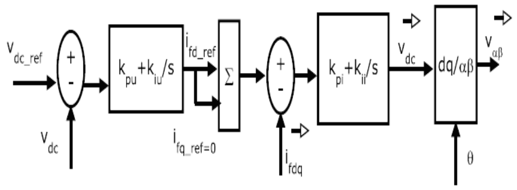

Figure 2.Block diagram of Mathematical Model of PI controller.

The capacitor also has to supply active power during transient states when the real-power demand of the load increases. Thus, in either case, the capacitor voltage drops. Similarly, the capacitor voltage will increase if the reactive/real power demand of the load decreases. Hence, by monitoring the capacitor voltage, the real power supplied by the APF can be estimated and the amplitude of the fundamental active component of the supply current has been estimated indirectly using the real-power balance theory. The control is on the supply current directly. Only one sensor is required to sense the supply current and there is no delay in the compensation process. A PI control algorithm is used to regulate the dc link voltage of the shunt APF. This method is preferred because the reference current is generated without calculating either the load current harmonics or the load reactive power. This results in an instantaneous compensation process and the associated hardware is simple to implement, thereby increasing system reliability. However, in this scheme, the nonlinear model of the APF system is assumed to be linear and the PI controller design is based on a mathematical model of the linearized system. Therefore Hysteresis current controller based scheme is to be investigated.

3.2 HYSTERESIS CURRENT CONTROLLER

Hysteresis-band PWM is basically an instantaneous feedback current control method of PWM where the actual current continually tracks the command current within a hysteresis band. Hysteresis control schemes are based on a nonlinear feedback loop with two level hysteresis comparators . The switching signals are produced directly when the error exceeds an assigned tolerance band. Hysteresis control schemes are based on a nonlinear feedback loop with two level hysteresis comparators. The switching signals are produced directly when the error exceeds an assigned tolerance band .Current error (generated due to the difference between APF compensating current and reference compensating current) movement if restricted within a specified boundary will help in compensating for harmonics. Researchers have worked upon application of space vector modulation based hysteresis current controllers for control of

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SAPF .. The control of APF can be realized by the hysteresis control technique. It imposes a bang-bang type instantaneous control that forces the APF compensation current (I_f) or voltage (v_f)signal to follow its estimated reference signal ($i_{f,ref}$ or $v_{f,ref}$) within a certain tolerance band. This control scheme is shown in a block diagram form in Figure 3. In this control scheme, a signal deviation (H) is designed and imposed on $I_{f,ref}$ or $V_{f,ref}$ to form the upper and lower limits of a hysteresis band. The I_f or V_f is then measured and compared with $I_{f,ref}$ or $V_{f,ref}$; the resulting error is subjected to a hysteresis controller to determine the gating signals when exceeds the upper or lower limits set by (estimated reference signal + $H/2$) or (estimated reference signal – $H/2$). As long as the error is within the hysteresis band, no switching action is taken. Switching occurs whenever the error hits the hysteresis band. The APF is therefore switched in such a way that the peak-to-peak compensation current/voltage signal is limited to a specified band determined by H as illustrated by4 Figure 4. The advantages of using the hysteresis current controller are its excellent dynamic performance and controllability of the peak-to-peak current ripple within a specified hysteresis band. Furthermore, the implementation of this control scheme is simple; this is evident from the controller structure shown in Figure 2. However, this control scheme exhibits several unsatisfactory features. The main drawback is that it produces uneven switching frequency. Consequently, difficulties arise in designing the passive HPF.

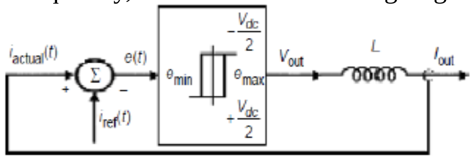
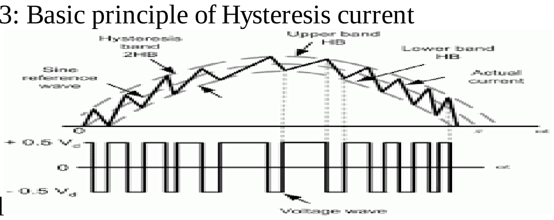


Figure3: Basic principle of Hysteresis current control



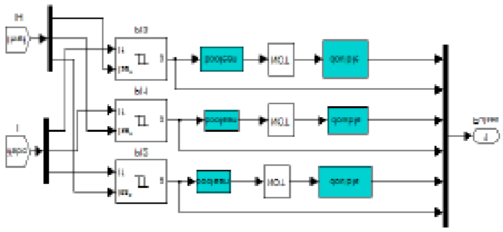


Figure4. block diagram of Hysteresis controller

Furthermore, there is possibly generation of unwanted resonances on the power distribution system . Besides, the irregular switching also affects the APF efficiency and reliability shown in Fig.3 .The ramping of the current between the two limits where the upper hysteresis limit is the sum of the reference current and the maximum error or the difference between the upper limit and the reference current and for the lower hysteresis limit, it is the subtraction of the reference current and the minimum error has been shown in Fig.4. Supposing the value for the minimum and maximum error should be the same. As a result, the hysteresis bandwidth is equal to two times of error.

$$\text{if } i_{Fa} \le (i^*_{Fa} - HB) \text{ then } T_1 = \text{'on' and, } T_2 = \text{'off'}$$
$$\text{if } i_{Fa} \ge (i^*_{Fa} + HB) \text{ then } T_1 = \text{'off' and } T_2 = \text{'on'} \quad 3.3$$

ADAPTIVE HYSTERESIS CURRENT CONTROLLER:

An adaptive hysteresis-band current control PWM technique can be programmed as a function of the active filter and supply parameters to minimize the influence of current distortions on a modulated waveform. The adaptive hysteresis band current controller changes the hysteresis bandwidth according to instantaneous compensation current variation *di/dt, fa* and *V*dc voltage to minimize the influence of current distortion on modulated waveform. An adaptive hysteresis based fuzzy logic controlled shunt active power filter has been studied to improve the power quality by compensating harmonics and reactive power requirement of the nonlinear load. Supply current is maintained sinusoidal in phase with supply voltage resulting in unity power Factor

MODELS DETAILS AND SIMULATIONS

The block diagram representation of the proposed control strategy for the shunt active filter is shown in Fig5 . The control strategy is implemented in three steps. In the first step, the required voltage and current signals are sensed to gather accurate system information. In the second step, reference compensating currents are derived based on instantaneous p-q theory. In the third step, the gating signals for the solid-state devices are generated using hysteresis-based current control method. The source is already modeled as ideal voltage source and remaining elements has been modeled in the following sessions.

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 6(a), 6 (b) 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 24.47% to 4.21%. 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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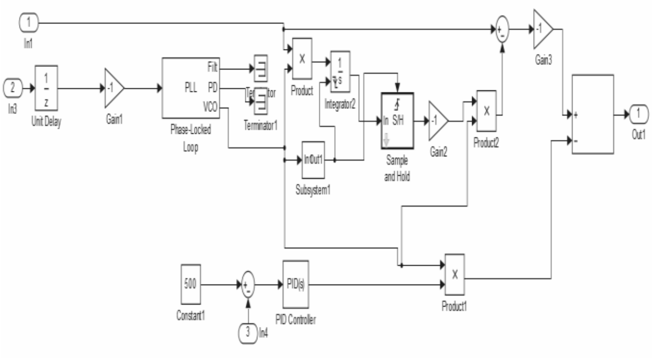

Figure 5.Control Scheme of Hysteresis Current Control

The D.C voltage across the capacitor is sensed and compared with reference it produces the error voltage. The error voltage is given to the proportional plus integral controller (PI) to get the peak value of charging current Isc, required to be absorbed by APF to charge the capacitor. The result is multiplied by unit sin wave to get the Instantaneous current. By adding the instantaneous current and compensating current we will get the reference current.

Performance Source Current THD without Filter:

The single phase line current in the absence of the filter is shown in Fig6(a). And Fig 6(b) shows the harmonic spectrum of the distorted waveform. The total harmonic Distortion(THD) of the distorted line current is 26.44%.

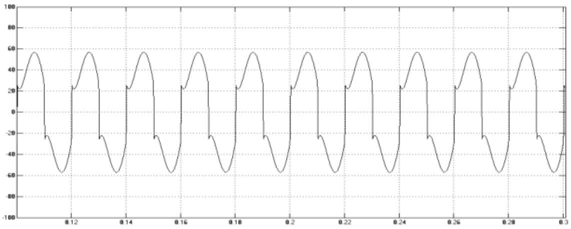

Figure 6(a)Source Current due to Non linear load

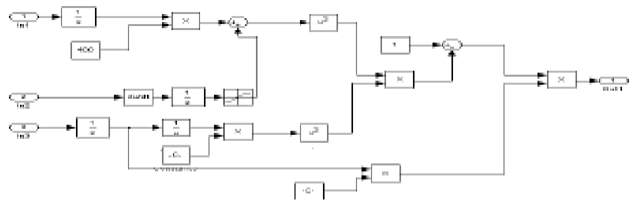

Fig 6(b).Simulink model for adaptive hysteresis band calculator

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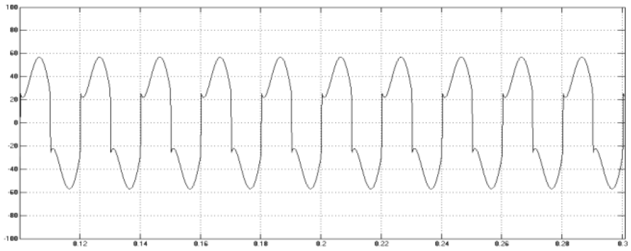

Figure 6(a)Source Current due to Non linear load

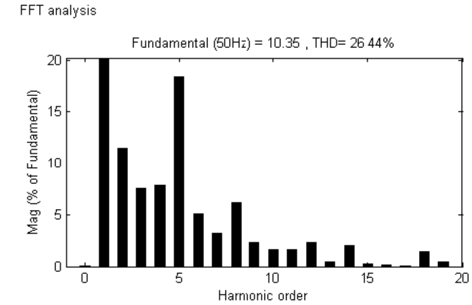

Figure6(c) shows the harmonic spectrum of the Current

(B)Performance with Fixed Hysteresis band current controller**:**

Fig 7 and Fig 8shows harmonic spectrums of source and load currents[8]. Fig.9 shows the DC bus Voltage With PIController We can observe that THD on source side has reduced from 26.47% to 4.28%. Thus results show APF with conventional control effectively compensates both harmonic and reactive powers.

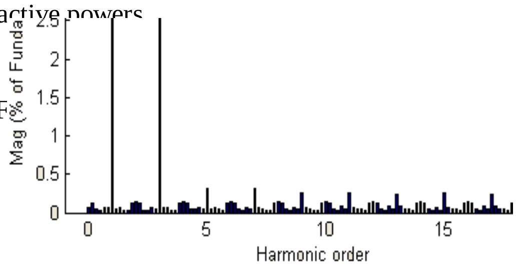

Figure 7. Harmonic spectrum of source current

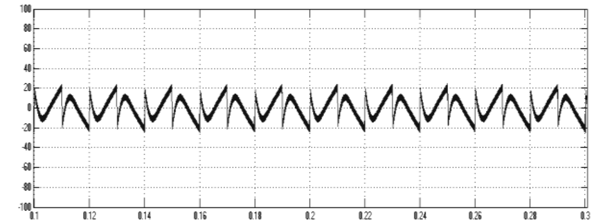

Figure 8.PWM injecting current.

Figure9. DC bus Voltage With PI Controller

(c)Performance with Adaptive Hysteresis band current Controller:

The source current, load current, harmonic injecting current and DC bus voltages are being shown after analysis. Fig 10 shows the harmonic spectrum of the current .Fig 11shows the harmonic spectrums of the load voltage . Fig 12 shows DC bus Voltage With Adaptive Hysteresis Controller . We can observe that THD on source side has reduced from 24.47% to 4.21%. Thus results show APF with adaptive hysteresis control effectively compensates both harmonic and

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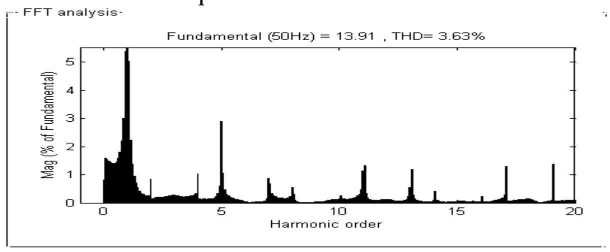

Figure10. shows the harmonic spectrum of the Current

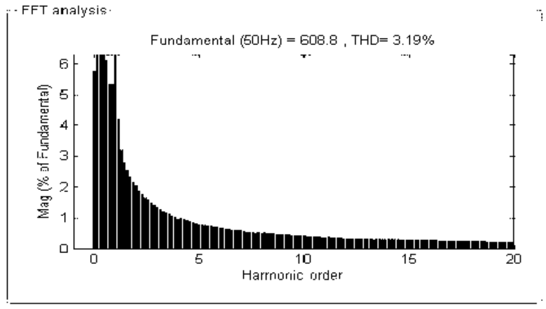

Fig. 11 shows the harmonic spectrum of the Source Voltage. It is observed that the DC bus voltage is exactly maintained at the reference value by the Adaptive Hysteresis controller, whereas some deviations are present with the PI Controller. In this method Harmonic content in the supply current has reduced and the THD has decreased from26.44 to 3.63% as shown . The shunt active power filters are the most suitable devices in power networks which eliminate the current harmonics and compensate the reactive power. The performance of the model for both conditions, with and without shunt active filter has been evaluated. The various waveforms for the PI control, hysteresis control, adaptive hysteresis control method are being analysed. With the proposed control algorithm the source current improves with the THD of 3.63% which is well within the standard. In order to perform the above task the capacitor voltage should have to be maintained and must be regulated by the algorithm. The proposed algorithm can properly regulate the capacitor voltage .The frequency of the hysteresis controller is kept 50Hz. These results show that source always remains sinusoidal and lower than the load currents.

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