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Implementation of Adaptive Hysteresis Current Controlled Shunt Active Filter For Non-Linear Loads

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Abstract: The use of nonlinear loads is increasing day by day. Application of these non-linear loads results in an increase in harmonic injection to the grid and low power factor which deteriorate the voltage quality waveforms. Active power filters (APFs) for both harmonic and reactive power compensation have found more attention in industrial applications for harmonic elimination and reactive power compensation. In this Project, an adaptive hysteresis band current controlled active power filter is implemented to eliminate harmonics at source due to three-phase rectifier. The adaptive hysteresis band current controller changes the bandwidth according to modulation frequency, supply voltage, dc capacitor voltage and slope of the reference compensator current wave thereby keeping the switching frequency constant. This controller can overcome the drawback of hysteresis current controller like switching losses, noise etc. Based on instantaneous power theory, harmonics components of load current are generated and used as reference current for APF to be compensated. The simulation of system is performed using Matlab-Simulink and Sim Power System toolbox and results are obtained

Index Terms: Shunt active power filter, Harmonic Reduction, Instantaneous reactive power theory, Adaptive hysteresis current control

I. INTRODUCTION

Non-linear loads such as such as rectifiers, power electronics converters, controllers for adjustable-speed motor drives, electronic power supplies, DC motor drives, battery chargers, electronic ballasts has been widely used.[1] Harmonic currents produced by these nonlinear loads are responsible for the rise in power quality related problems .These nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system. Harmonic currents produced by nonlinear loads are injected back into power distribution systems through the point of common coupling (PCC). As the harmonic currents pass through the line impedance of the system, harmonic voltages appear, causing distortion at the PCC. Harmonic currents produced by these nonlinear loads causes distortion in a power distribution system[2].
RLC passive filters have been used to eliminate lower and specific order harmonics of non-linear loads.

Passive filters consisting of capacitors, inductors and/or resistors can be classified into tuned filters and high-pass filters. Passive filter provide low-impedance paths for specific harmonic frequencies, thus resulting in absorbing the dominant harmonic currents flowing out of the load. Even though they are cheap, passive filters posses many disadvantages like tuning problems, series and parallel resonance, uncontrollable power factor and reactive power injection[3].
Recently, active power filters (APFs) for both harmonic and reactive power compensation have found more importance in industrial applications than passive filters.[4] They are smaller in physical size, more flexible and have better performance than passive filters. There are mainly three types of active filters- shunt, series and hybrid. Among the three filters shunt active filters have been used for harmonic compensation .This is because most of the industries require current harmonic compensation[5]. The structure and controller which generate switching pattern and the method to extract the reference current from the distorted line current affect the performance and quality of the APF[8].

Several methods to extract the reference signal have been proposed. Among all, the instantaneous power theory shows advantages such as simplicity in implementation and also the ability to come up with different ways of computing the reference current [6],[7].

Various current control methods are proposed for shunt active power filter. among the current control methods hysteresis band current control method has the highest rate due to its quick current controllability and easy implementation[8]. PI controller is provided for inverter DC bus voltage regulation. But hysteresis current control show some disadvantages due to its control with variable switching frequency .These disadvantages include switching losses, audible noise and EMF related problems[9].

Adaptive hysteresis current control method has been proposed to overcome the disadvantages of conventional hysteresis current control. Adaptive hysteresis band current controller changes the hysteresis band width according to reference current to make switching frequency of inverter nearly constant and further reduce the THD of supply current [10].

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The main objective of the project is to implement an adaptive hysteresis current controller for shunt active filter for non linear loads and also to analyze and compare the THD of conventional method and proposed method. Adaptive hysteresis current controller reduces the harmonic components of load current of non linear load. It also reduces the switching losses occurred while using hysteresis current controller due to a variation in switching frequency thereby improving the performances of shunt active filter.

II. SYSTEM DESCRIPTION

General schematic diagram of the system is shown in Fig 1. A current controlled voltage source inverter is used to generate the compensating current and is injected into the utility power source grid. This cancels the harmonic components drawn by the non-linear load and keeps the utility line current sinusoidal. Instantaneous reactive power theory based algorithm is proposed for reference signal generation. The reference current calculator will extract the reactive and harmonic current component of the load current and generate the compensating current. Depending upon error (Vdcref - Vd), PI controller will determine the necessary active component of current to be absorbed by APF from supply in order to maintain D.C. bus voltage. The resultant reference current, 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. HB can be varied as a function of diref*/dt and Vdc to maintain frequency. The hysteresis current controller tracks the reference current iref by generating device switching signals to control ramping of current, in the coupling inductor L, within hysteresis band, HB.

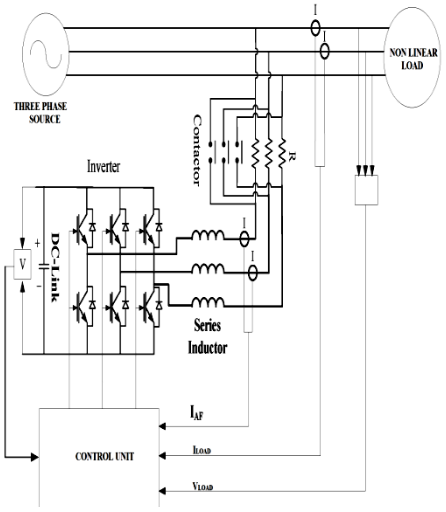

Fig 1 : Schematic Diagram of the System[8]

III. INSTANTANEOUS REACTIVE POWER THEORY FOR REFERENCE SIGNAL GENERATION

The instantaneous power theory is used for reference signal generation. The three phase voltages and currents are transferred into α-β reference frame as follows:

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \text{--------- (1)}$$

The active and reactive power are then obtained as

$$p = e_\alpha i_\alpha + e_\beta i_\beta$$
$$q = -e_\beta i_\alpha + e_\alpha i_\beta \text{ --------- (2)}$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \text{---------- (3)}$$

Since the currents are harmonic polluted or imbalanced, other components will appear in the active and reactive powers.
therefore

$$p = \overline{p} + \tilde{p}$$
$$q = \overline{q} + \tilde{q} \text{ ----------- (4)}$$

Where:

- $\overline{p}$ and $\overline{q}$ are constant active and reactive powers referring to balanced and non-harmonic polluted currents,
- $\tilde{p}$ and $\tilde{q}$ are active and reactive power ripples referring to imbalanced and harmonic polluted currents.

To make the network currents sinusoidal, the active and reactive power ripples should be compensated by the APF.. Accordingly, the APF's active and reactive power reference are given:

$$P_{APF,ref} = \tilde{P}$$
$$Q_{APF,ref} = \tilde{Q} + k\tilde{q} \text{ ---------- (5)}$$

Based on the equations (4) and (5), the compensating currents on α-β coordinates are calculated as:

$$\begin{bmatrix} i^*_{APF,\alpha} \\ i^*_{APF,\beta} \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} P_{APF,ref} \\ Q_{APF,ref} \end{bmatrix} \text{-----------(6)}$$

Using α-β ➔ a-b -c transformation, the APF reference currents in the a-b-c coordinates are calculated as:

$$\begin{bmatrix} i^*_{APF,a} \\ i^*_{APF,b} \\ i^*_{APF,c} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \sqrt{\frac{3}{2}} \\ \frac{-1}{2} & -\sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} i^*_{APF,\alpha} \\ i^*_{APF,\beta} \end{bmatrix} \text{--(7)}$$

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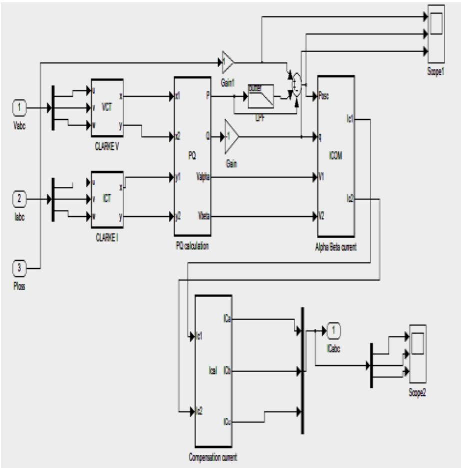

Fig 2: Simulation diagram for reference signal generation

IV. CONVENTIONALCURRENTCONTROL

The hysteresis-band current control method is popularly used because of its simplicity of implementation, among the various PWM techniques. Besides fast-response current loop and inherent-peak current limiting capability, the technique does not need any information about system parameter. The switching logic for inverter control is formulated as follows:

If ic< (ic*− HB) upper switch is OFF and lower switch is ON

If ic > (ic* + HB) upper switch is ON and lower switch is OFF

where ic is the filter current and ic* is the reference current and HB is the hysteresis band width. However, the current control with a fixed hysteresis band has the disadvantage that the switching frequency varies with in a band because peak-to-peak current ripple is required to be controlled at all points of the fundamental frequency wave. But interesting improved versions of this technique are presented.

V. PROPOSED CURRENT CONTROL

The adaptive hysteresis band current controller changes the hysteresis bandwidth according to instantaneous compensation current variation (dic/dt) and Vdc voltage to minimize the influence of current distortion on modulated waveform and to optimize switching frequency and THD of supply current[6].

$$HB = \left\{ \frac{0.125V_{dc}}{f_c L}\left[1 - \frac{4L^2}{V_{dc}}\left(\frac{v_s}{L} + m\right)^2\right]\right\}$$

The above equation shows the hysteresis bandwidth (HB) as a function of modulation frequency, supply voltage, dc capacitor voltage and slope of the reference compensator current wave. Hysteresis band can be modulated as a function of Vdc and m so that the modulation frequency fc remains nearly constant. This will improve the PWM performances and APF substantially.

VI. CALCULATIONOF HYSTERESIS BANDWIDTH

Hystresis band width can be calculated as fucntion of modulation frequency, supply voltage, dc capacitor voltage and slope of the reference compensator current wave.

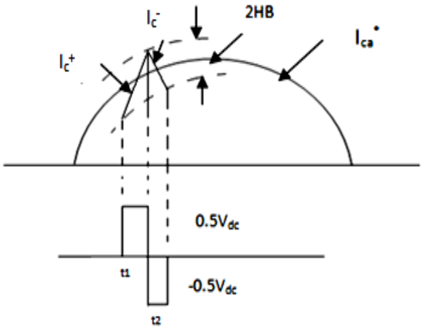

Fig 3:PWM current and voltage waveforms for phase a[9]

Fig. 3 shows the PWM current and voltage waves for phase a. The currents ia tends to cross the lower hysteresis band at point 1, where upper side IGBT of leg "a" is switched on. The linearly rising current (ica) then touches the upper band at point 2, where the lower side IGBT of leg "a" is switched on. The following equations can be written in the respective switching intervals t1 and t2 from Fig 3

$$\frac{di_{ca}^{+}}{dt} = \frac{1}{L}\left(0.5V_{dc} - V_s\right)\ldots\ldots\ldots\ldots(1)$$

$$\frac{di_{ca}^{-}}{dt} = \frac{1}{L}\left(0.5V_{dc} + V_s\right)\ldots\ldots\ldots\ldots(2)$$

From the geometry of Fig 7.2, can be written

$$\frac{di_{ca}^{+}}{dt}t_1 - \frac{di_{ca}^{*}}{dt}t_1 = 2HB\ldots\ldots\ldots(3)$$

$$\frac{di_{ca}^{-}}{dt}t_2 - \frac{di_{ca}^{*}}{dt}t_2 = 2HB\ldots\ldots\ldots(4)$$

$$t_1 + t_2 = T_c = \frac{1}{f_c}\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where t1 and t2 are the respective switching intervals and fc is the switching frequency.

Adding (3) and (4) and substituting in (5) ,it can be written

$$t_1\frac{di_a^{+}}{dt} + t_2\frac{di_a^{-}}{dt} - \frac{1}{f_c}\frac{di_{ca}^{*}}{dt} = 0\ldots\ldots\ldots(6)$$

Subtracting (4) from (3) we get

$$4HB = \frac{di_{ca}^{+}}{dt}t_1 - \frac{di_{ca}^{-}}{dt}t_2 - (t_1 - t_2)\frac{di_{ca}^{*}}{dt}\ \ldots..(7)$$

Substituting (1) and (2) in (7),simplifying

$$t_1 - t_2 = \frac{1}{f_c}\frac{di_{ca}^{*}/dt}{di_{ca}^{*}/dt}\ldots\ldots\ldots\ldots(8)$$

Substituting (8) in (7) we get ,

$$HB = \left\{ \frac{0.125V_{dc}}{f_c L}\left[1 - \frac{4L^2}{V_{dc}}\left(\frac{v_s}{L} + m\right)^2\right]\right\}\ldots(9)$$

where fc is modulation frequency, m = dica/dt is the slope of command current wave. Hysteresis band (HB) can be

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modulated at different points of fundamental frequency cycle to control the switching pattern of the inverter.

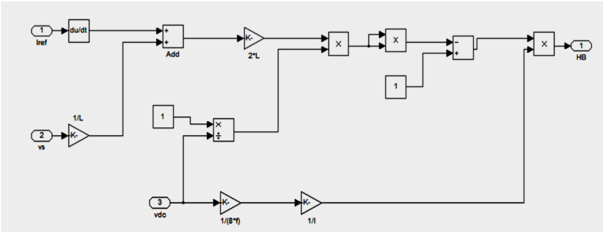

Fig 4 : Simulation diagram for hysteresis band width calculation

VII. SIMULATION ANALYSIS

Simulation of system is performed using mat lab. The output and the intermediate waveforms are obtained. MATLAB 7.10.0(R2010a) is used for simulation part of the project. The non linear load taken is a three phase diode bridge rectifier with RL load. The parameters of the simulated system are given in Table I

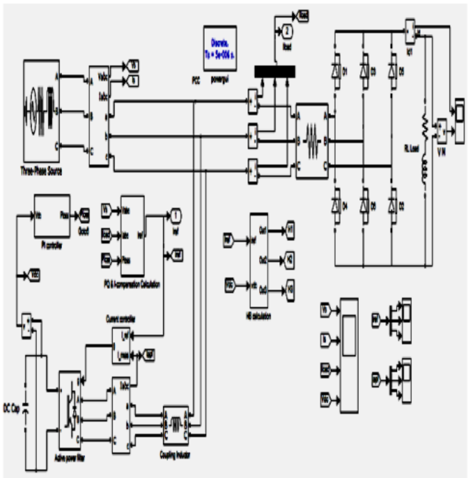

Fig 5: Simulation diagram of the system compensated by a shunt active filter through a proper control

TABLEI : SYSTEM PARAMETERS

Source voltage	415V
System frequency	50Hz
DC link voltage	800V
DC capacitance	5000 µF
Coupling inductance	1.5mH
AC side resistance	1Ω
Load parameters	Rl =10Ω Ll=80mH

VIII. RESULT

FFT analysis is done to obtain the THD of the current waveform. The THD of the uncompensated system was obtained to be 30.78%. A comparison between THD of the supply while using hysteresis control and adaptive hysteresis current control has been done . It can be found that when the control changes from the conventional method to proposed method the THD of supply current changes from 6.36% to 3.94%. Also waveforms of source current ,load current , filter current , reference current and regulated DC bus voltage has been obtained and shown in figures below

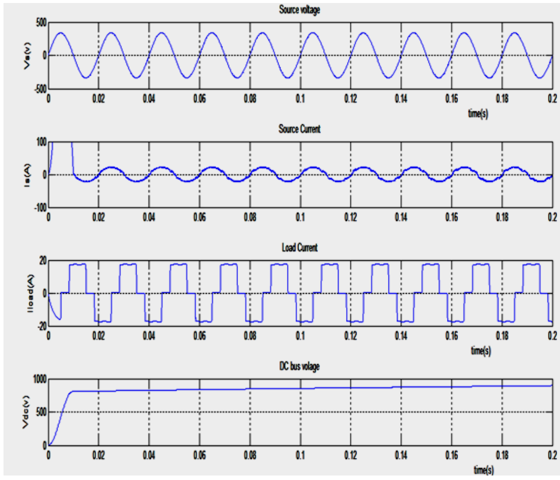

Fig 6: Simulation results (i)source voltage (ii)source current (iii) load current and (iv) Dc bus capacitor voltage after providing compensation

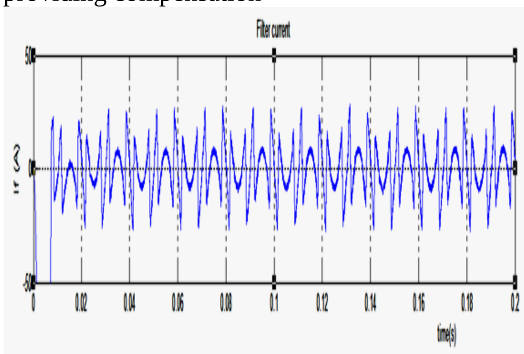

Fig 7: Simulation waveform of filter current

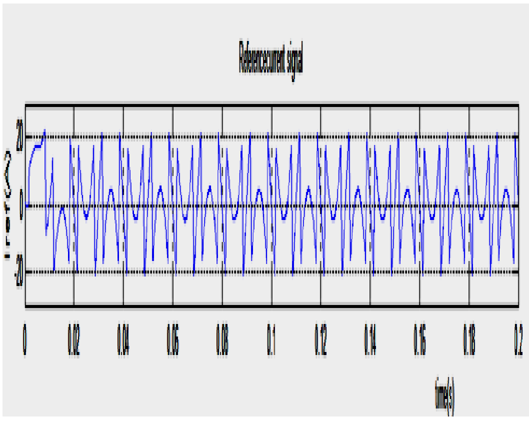

Fig 8: Reference signal current for compensation

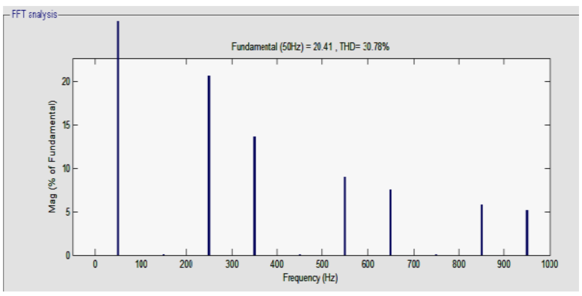

Fig9:THD analysis of supply current of the uncompensated system

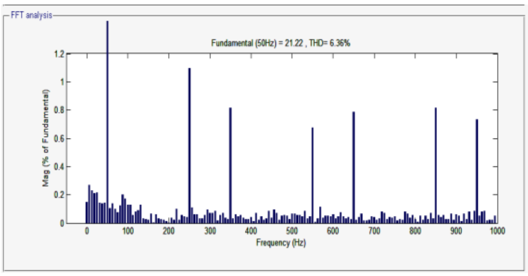

Fig10: THD analysis of source current of the system compensated by hysteresis current controlled shunt active filter

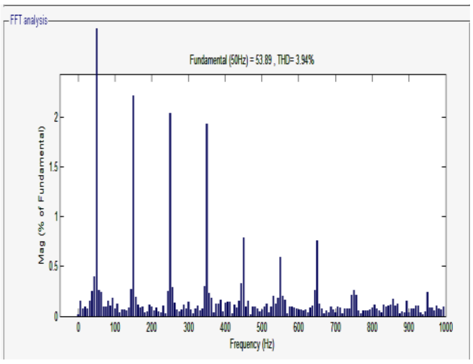

Fig 11:THD analysis of source current of the system compensated by adaptive hysteresis band current controlled shunt active filter

IX. CONCLUSION

Shunt active power filter with a suitable control can be used to reduce harmonics on the system due to a non-linear load. When hysteresis current control was used to control the switching of the shunt active filter THD of the source current was obtained as 6.55%. But due to variation in switching frequency losses also occurs. Adaptive hysteresis current controller can be successfully employed for making the switching frequency of the voltage source inverter nearly constant, thereby overcoming the disadvantage of conventional hysteresis controller. By using Adaptive hysteresis current controller, the THD of supply current is reduced to 2.62% which is well within the limits specified by the standards. Adaptive control optimizes the switching frequency of the inverter and THD of source current there, by providing better performance for the shunt active filter.

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