Instantaneous reactive power theory active power line conditioner

Utsav Sharma, Sumit Kharbanda

M.E. Scholar, Dept. of Electrical Engineering,
PEC University of Technology, Chandigarh, India

Abstract - *This study presents the results of active power line conditioner with hysteresis controller using instantaneous reactive power theory(IRPT). Total harmonic distortion (THD) is taken as a measuring quantity of power quality. In results, THD of different phases is shown. Also, different frequency components are tabulated for the harmonically unbalanced load.*

Key Words*: *active power line conditioner; pq theory; hysteresis controller; Simulation; Unbalancing

1.INTRODUCTION

Increased uses of power electronics devices introduce the harmonics due to which poor power quality is a major concern nowadays. Switching of nonlinear load introduces harmonics in the source current due to which another load connected to the same grid affects. To mitigate these harmonics we use filters. Many researchers and scientists reported the design of filters using different techniques. Passive filters are the introductory method to mitigate harmonics. Tuning of passive filters is the most important criteria but due to ageing effect, it detunes. Also for some frequencies, passive filters have the phenomenon of resonance and that particular harmonic amplifies. To solve these problems active power line conditioner (APLC) are introduced to improve the power quality.

For better results, power conditioners are based on precise calculation of load current. Akagi et al give the instantaneous reactive power theory. The author introduced the concept of instantaneous imaginary power q for the three-phase circuit. To detect the instantaneous reactive power without any delay this method is proposed. A generalized theory of instantaneous reactive power had been proposed for three-phase systems[1]. This work is proposed to resolve the limitations of IRPT by Akagi. Assessment of different approaches for active power filter compensation is done by [2]–[7].

Power conditioners are used not only to mitigate the harmonics while to improve the overall power quality. In APLC, extraction of reference current from the load current is important, and then effective control strategy is being used to control the switching of the inverter so that inverter commands the exact current to the source. Study of different controllers has been done [8]. Overall hysteresis controller is the simplest and the results of the comparison showed the superiority of the hysteresis control[9]. As analog control techniques have the fastest speed in comparison with the digital control techniques, because there is no delay by any A/D conversion process.[9]–[11] For these facts and according to the practical experience, the hysteresis control have been considered in this paper.

2. INSTANTANEOUS REACTIVE POWER THEORY

2.1 Clarke's Transformation

Three phase load currents and voltages i.e. ia, ib, ic and va, vb, vc are transformed into αβ co-ordinates using Clarke's transformation.

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

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (2)$$

2.2 Calculation of Compensating Power and Current

Instantaneous power is calculated using currents and voltages in αβ co-ordinates.

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

Calculated active power p and reactive power q comprises of two components.

$$p = \hat{p} + \overline{p} \quad (4)$$

$$q = \hat{q} + \overline{q} \quad (5)$$

Here $\hat{p}$ and $\hat{q}$ are the oscillating components and $\overline{p}$ and $\overline{q}$ are the average value component of the instantaneous active and reactive power consequently. Average parts are the cause of the fundamental value and oscillating parts are the cause of harmonics.

We compensated all the harmonics using APLC, so we extract $\hat{p}$ and $\hat{q}$ from the calculated power.

$$\hat{p} = (p - \overline{p}) \quad (6)$$

$$\hat{q} = (q - \overline{q}) \quad (7)$$

2.3 Calculation of compensating current

Compensating current is calculated using compensating power in terms of αβ co-ordinates.

$$\begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix} = \left(\frac{1}{v_\alpha{}^2 + v_\beta{}^2}\right) \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} \hat{p} \\ \hat{q} \end{bmatrix} \quad (8)$$

Using inverse Clarke's transformation, i^*_α and i^*_β is converted into i^*_a, i^*_b, and i^*_c.

$$\begin{bmatrix} i^*_a \\ i^*_b \\ i^*_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix} \quad (9)$$

3. HYSTERESIS CONTROLLER

Current control (CC) techniques for voltage source inverters (VSI) can be divided into linear (stationary, synchronous, and predictive deadbeat) controllers and nonlinear (hysteresis etc.) controllers. Among all CC techniques hysteresis is simplest to implement and gives more appropriate results. Reference current is compared with hysteresis band. When current goes down the lower (upper) limit of hysteresis band upper (lower) switch of VSI is ON.

4. SYSTEM CONFIGURATION

Fig.1 shows the schematic layout of the proposed Active Power Line Conditioner system aimed at removing current harmonics. The active filter is basically a three phase IGBT inverter bridge with a voltage source on its DC side. Active filter is switched through the hysteresis controller.

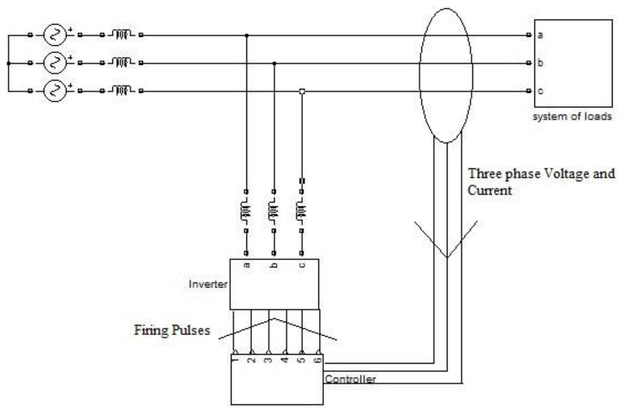

Fig. 1. Basic schematic layout of the proposed sytem

5. SIMULINK RESULTS

A MatLab/SIMULINK model has been developed (Fig.2) and is simulated under a range of variations of the passive filter values and the source frequency. The system is simulated using the ode45 solver with a sample time of 1µs. The source inductance is kept at 1µH with source line voltage V_{L-L} kept at 415V. The non-linear load is an uncontrolled diode rectifier with R-L load on the DC side. In the present example, the load draws non-linear current of amplitude 40A maximum from the three phase grid. A three phase VSI is connected in series with the grid using smoothing inductor.

TABLE I. TABLE FOR VALUES OF ELEMENTS USED

S.No.	Elements	Values of the elements
1	AC Voltage Source	$325V_{max}$/phase
2	Source inductance	1µH
3	DC link voltage(DCV)	750V
4	DC link Inductance	1mH

5.1 Operation without APLC

This system of load is creating an unbalance 3-phase system (shown as abc). A single phase rectifier is connected between the phase a and phase b and the voltage controller is connected between the b-c phases. Total harmonic distortion (THD) is chosen as the measured quantity for power quality.

Table II shows the value of current harmonics on different phases. Different values of current at different phases show the current unbalancing.

TABLE II. VALUE OF CURRENT AT DIFFERENT PHASES WITHOUT APLC

	Load		
	Phase a	**Phase b**	**Phase c**
Fundamental	34.99	35.09	35.21
3rd Harmonics	3.59	4.81	1.36
5th Harmonics	4.47	2.61	2.72

5.2 Operation with APLC

Table III shows the values of source current and current given by APLC or compensator current in different phases. APLC is working on the working principal of instantaneous reactive power theory and hysteresis controller.

TABLE III. VALUE OF CURRENT AT DIFFERENT PHASES WITH APLC

Current	Source			Compensator		
	Phase a	Phase b	Phase c	Phase a	Phase b	Phase c
Fundamental	28.51	28.14	27.88	11.17	11.75	12.68
3rd Harmonics	0.15	0.08	0.21	3.50	4.80	1.52
5th Harmonics	0.06	0.15	0.09	4.42	2.46	2.76

Table IV shows the %THD value at different phase. As THD is less than IEEE recommended 5% value, it is an satisfactory method to be implemented.

TABLE IV. %THD AT DIFFERENT PHASES

Phases	%THD
a	2.84
b	2.92
c	1.99

6. WAVEFORMS

6.1 Source current waveforms without APLC

Fig. 4 is showing source current waveform of phase a without using APLC. This distortion is due to harmincs injected through switching load(power electronics load). To mitigate this distortion proposed method removes harmonics from the source current waveform.

Fig. 5 is showing the source current waveform after using APLC. Source current waveform in fig. 5 is showing that there is no harmonics. These current notches are due to high frequency switching of APLC, to mitigate them current low pass filter will be used in hardware circuit.

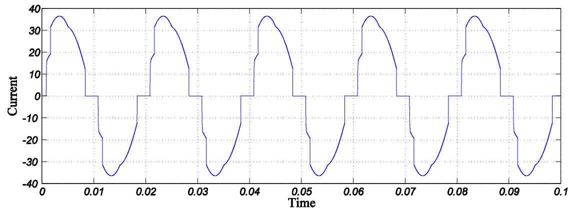

Fig. 2. Source current waveform without APLC

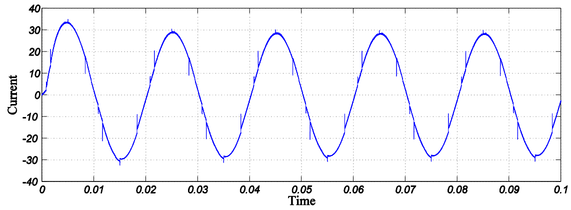

Fig. 3. Source current waveform with APLC

7. CONCLUSION

Instantaneous reactive power theory and hysteresis-band current control technique has been described in the paper. A hysteresis-band current control method is popularly used because it is simple to implement and gives the near to accurate results. Instantaneous reactive power theory is a popular choice among design engineers in balanced condition because of it is simple to implement. Results of APLC using both have been shown in above tables and waveforms are shown also.

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