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Power Quality Improvement of Three Phase System using Shunt Active Power Filter

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Abstract: A power quality issue basically deals with any occurrence manifested in current, voltage or frequency deviation that results in damage, upset or failure of end use equipment. The non-linearity in the properties of power electronics devices and the higher switching frequency are the main causes of power quality issue. Thus this paper deals with power quality improvement by shunt active power filter to eliminate voltage and load current harmonics and for reactive power compensation. A shunt active power filter based on the instantaneous active and reactive current component (Id – Iq) method is proposed to compensate first harmonic unbalance. A theoretical studies based on synchronous detection method is done in this paper and the simulation results are analyzed regarding the harmonics compensation. Simulations are carried out with PI controller for the (Id – Iq) control strategies for different voltage condition using MATLAB/ SIMULINK.

Keywords: Harmonic distortion, shunt active power filter, (p-q) and (Id-Iq) control strategies, PI controller.

I. INTRODUCTION

Most of the social and economic activity depends on electrical energy quality and efficiency. The use of non-linear load generates current and voltage harmonics which detoriates the power quality. Thus mitigation of harmonics is necessary. The non-sinusoidal currents drown from the ac mains by the non-linear loads cause reactive power burden and excessive neutral current their by reducing efficiency of the system. Since the beginning of 1980's active power filters have been accepted as most common compensession method. The shunt connected active power filter with a self-controlled DC bus used for reactive power compensession in power transmission system. SAPF compensate load current harmonics by injecting equal but opposite harmonic compenseting current.

The work presented mainly focus on p-q and Id-Iq control strategies using PI controller and hysteresis controller. Instantaneous active and reactive theory (p-q theory) was introduce by H. Akagi, Kawakawa and Nabae in 1984. Both p-q and Id-Iq methods are compared for distorted main voltage conditions and the Id-Iq control method comes out to be superior in harmonic compensession performance. MATLAB software simulation is done in Simulink power system for analysis of the performance of compensession methods.

II. SHUNT ACTIVE POWER FILTER CONFIGURATION

The active filters operations are based on injection of harmonics required by load. Modern harmonic filters are superior in filtering performance, smaller in physical size and more flexible in application. The active filters are slightly inferior in cost and operating loss, compared to passive filter. To employ active power filter in three phase four wire system, we have used the configuration of three leg structure with the neutral conductor being connected to midpoint of DC link capacitor. The higher order harmonics generated in the eight switch configuration due to frequent switching of semiconductor devices can be eliminated by the use of RC high pass filter. The three leg six switch split capacitor configuration of SAPF suffers several shot comings:

1) Control circuit is somewhat complex.
2) Voltage of tow capacitor of split capacitor needs to be properly balanced.
3) Large DC link capacitors are required.

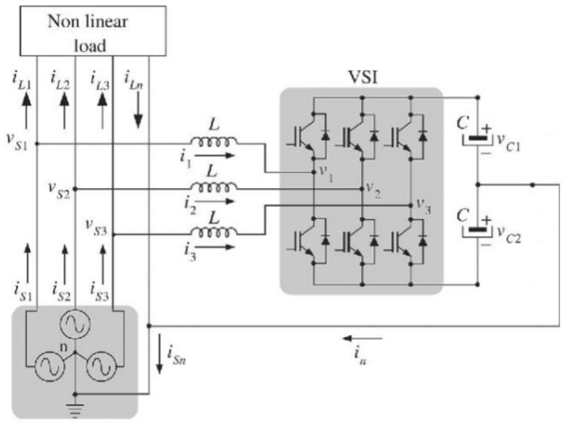

Figure (1): Three leg shunt active power filter with non-linear load

III. INSTANTANEOUS ACTIVE AND REACTIVE POWER (p-q) METHOD

The control algorithm block diagram for p-q method is depicted in **Figure (1).** The three-phase source voltages

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(v_{sa}, v_{sb}, v_{sc}) and load currents (i_{La}, i_{Lb}, i_{Lc}) in the a-b-c coordinates are algebraically transformed to the α-β co-ordinates using Clarke's transformation as per (1) and (2), followed by the calculation of the instantaneous active power (p) and reactive power (q) by following (3).

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

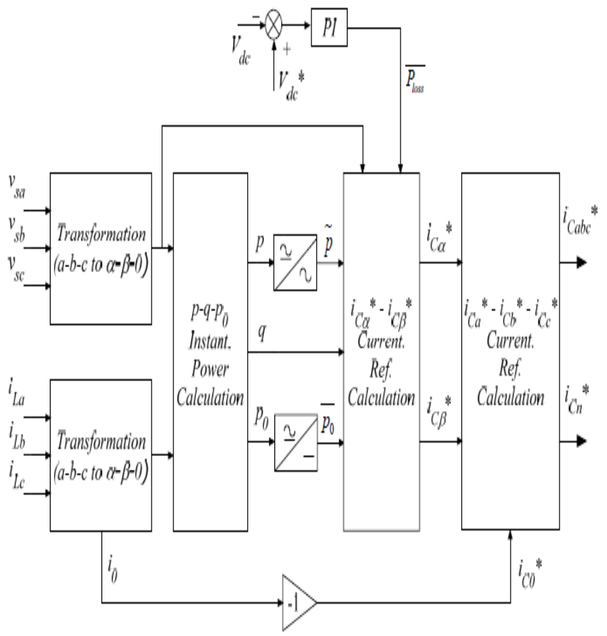

Figure (2):Reference current extraction with conventional p-q method.

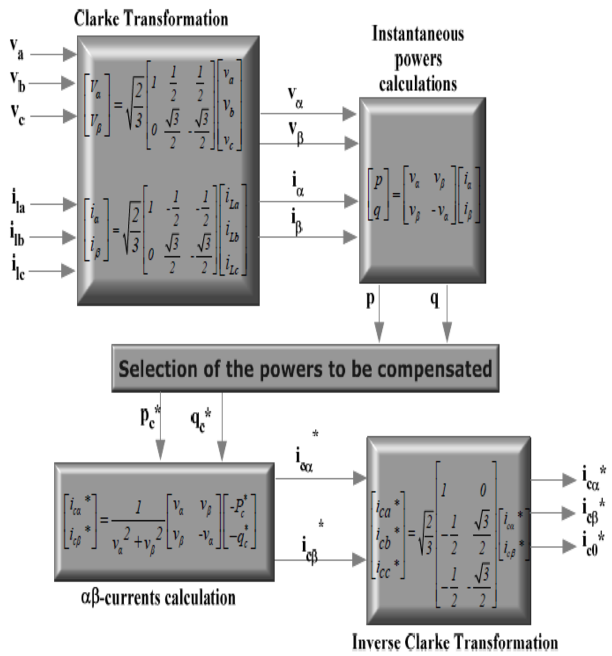

Figure (3): Control method for Shunt current compensation based on p-q theory

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{L_a} \\ i_{L_b} \\ i_{L_c} \end{bmatrix} \quad (2)$$

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

Each of these powers has dc component (1st component) and ac component (2nd component) as shown in (4).

$$p = \bar{p} + \tilde{p}$$
$$q = \bar{q} + \tilde{q} \quad (4)$$

For reactive and harmonic compensation, the entire reactive power and ac component of active power are utilized as the reference power. The reference currents in α-β coordinates are calculated by using (5).

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -p_c^* \\ -q_c^* \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \quad (6)$$

In addition PLL (Phase locked loop) employed shunt filter tracks automatically, the system frequency and fundamental positive-sequence component of three phase generic input signal. Appropriate design of PLL allows proper operation under distorted and unbalanced voltage conditions. Controller includes small changes in positive sequence detector as harmonic compensation is mainly concentrated on three phase four wire [9]. As we know in three-phase three wire, V_a, V_b,$V_c$are used in transformations which resemble absence of zero sequence component and it is given in Equation (7). Thus in three phase four wire it was modified as V_α', V_β' and it is given in Equation (8).

$$\begin{bmatrix} v_a' \\ v_b' \\ v_c' \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_\alpha' \\ v_\beta' \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} v_\alpha' \\ v_\beta' \end{bmatrix} = \frac{1}{i_\alpha'^2 + i_\beta'^2} \begin{bmatrix} i_\alpha' & -i_\beta' \\ i_\beta' & i_\alpha' \end{bmatrix} \begin{bmatrix} \bar{p}' \\ \bar{q}' \end{bmatrix} \quad (8)$$

IV. INSTANTANEOUS ACTIVE AND REACTIVE CURRENT METHOD (Id-Iq)

The load currents i_{La}, $i_{Lb}$and $i_{Lc}$are tracked upon which Park's transformation is per-formed to obtain corresponding d-q axes currents $i_{Ld}$and i_{Lq}as given in (9), where ω is rotational speed of synchronously rotating d-q frame. According to id-iqcontrol strategy, only the average value of d-axis component of load current should be drawn from supply. Here $i_{Ld1h}$and i_{Lq1h}indicate the fundamental frequency component of $i_{Ld}$and i_{Lq}. The oscillating

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components i_{Ld} and i_{Lq}, i.e., i_{Ldnh} and i_{Lqnh} are filtered out using low-pass filter.

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} i_{Ld\,1h} & i_{Ldnh} \\ i_{Lq\,1h} & i_{Lqnh} \end{bmatrix}$$

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \sin wt & \cos wt \\ -\cos wt & -\sin wt \end{bmatrix} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (9)$$

The currents i_{Ldnh} and i_{Lqnh} along with i_{d1h} are utilized to generate reference filter currents i_{cd}* and i_{cq}* in d-q coordinates, followed by inverse Park transformation giving away the compensation currents i_{ca}*, i_{cb}*, i_{cc}* and i_{cn}* in the four wires as described in (10) and (11).

$$\begin{bmatrix} i^*_{ca} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \begin{bmatrix} \sin wt & \cos wt & 1 \\ \sin\left(wt - \frac{2\pi}{3}\right) & \cos\left(wt - \frac{2\pi}{3}\right) & 1 \\ \sin\left(wt + \frac{2\pi}{3}\right) & \cos\left(wt + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} i^*_{cd} \\ i^*_{cq} \\ i^*_{c0} \end{bmatrix} \quad (10)$$

$$i^*_{cn} = i^*_{ca} + i^*_{cb} + i^*_{cc} \quad (11)$$

The reference signals thus obtained are compared with the actual compensating filter currents in a hysteresis comparator, where the actual current is forced to follow the reference and provides instantaneous compensation by the APF [10] on account of its easy implementation and quick prevail over fast current transitions. This consequently provides switching signals to trigger the IGBTs inside the inverter. Ultimately, the filter provides necessary compensation for harmonics in the source current and reactive power unbalance in the system.

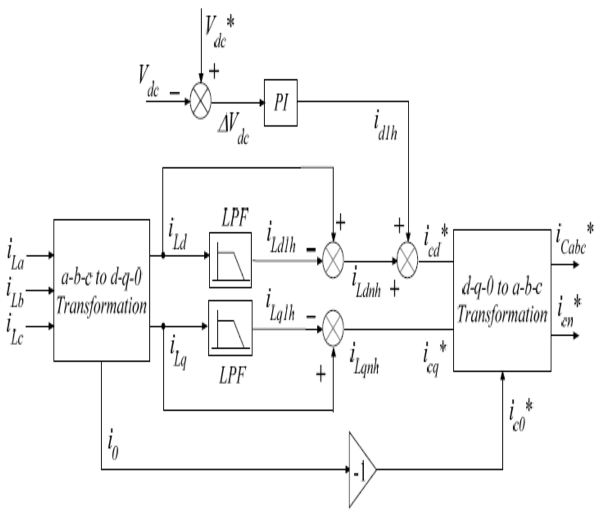

Figure (4): Reference current extraction with Id-Iq method

V. PI CONTROLLER

PI control is needed for non-integrating processes, meaning any process that eventually returns to the same output given the same set of inputs and disturbances. A P-only controller is best suited to integrating processes. The control scheme of our system consist of PI controller, limiter, three phase sin wave generator for reference current generation and generation of switching signal. The DC link voltage regulates the peak value of reference current. The actual capacitor voltage is thus compared with the reference values. The PI controller processes the error signal which results in zero steady error in tracking the reference current signal. The output of PI controller is taken as peak value of system current (I_{max}), which is composed of to components i.e. the fundamental active power component of load current and the loss component of active power filter; to maintain the average capacitor voltage to a constant value. The I_{max} is multiplied by the unit sign vector in phase with the respective source voltages to obtained the reference compensating current.

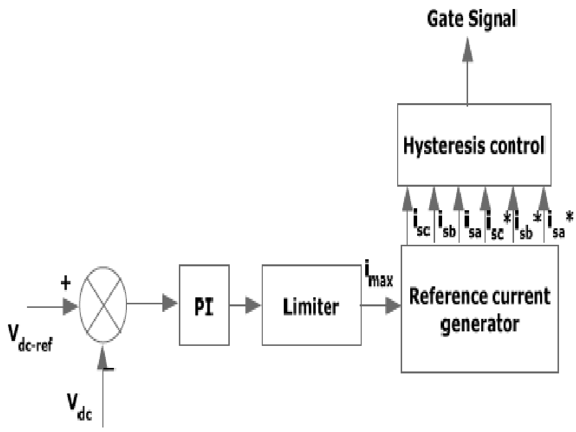

Figure (5): Conventional PI controller.

The estimated refer-ence currents (Isa*, Isb*, Isc*) and sensed actual currents (Isa, Isb, Isc) are compared at a hysteresis band, which gives the error signal for the modulation technique. Thus the operation of convertor switches is excited by the error signals. In this current control circuit configuration, the source/supply currents Isabcare made to follow the sino-soidal reference current Iabc, within a fixed hysteretic band. The width of hysteresis window determines the source current pattern, its harmonic spectrum and the switching frequency of the devices.

VI. CONCLUSION

Thus the paper gives the idea of improvement in power quality using shunt active power filter. Basically we calculated the refrence current values of the system using active and reactive power and current control strategies with the help of PI controller. Now these reference current values are compared to the main current (system current) values by using hysteresis comparator and thus the resultant value of current to the shunt active power filter. Hence the compensating current is injected in the system through the three leg SAPF. Hence using P-Q technique

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and SAPF the quality or the stability of the system is increase and we have stable and error free system.

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