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INVESTIGATION ON SHUNT ACTIVE POWER FILTER USING PI CONTROLLER

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ABSTRACT

This paper describes the application of PI controller to a three phase shunt active power filter for power quality improvements and reactive power compensation required by a nonlinear load. Most active power filter use PI controller in the voltage/current control loop. The use of PI controller is simple and easy to implement. However, the design of PI controller requires a precise linear mathematical model. Switching signals for voltage sourced PWM converter are generated through hysteresis current control. The performance of shunt active power filter is evaluated using MATLAB/SIMULINK simulation.

KEYWORDS- shunt active power filter (SAPF), Power quality, PI controller, % THD..

INTRODUCTION

In modern electrical distribution systems there has been a sudden increase of single phase and three-phase non-linear loads. These non-linear loads employ solid state power conversion and draw non-sinusoidal currents from AC mains and cause harmonics and reactive power burden, and excessive neutral currents that result in pollution of power systems. They also result in lower efficiency and interference to nearby communication networks and other equipments.

Active power filters have been developed to overcome these problems. Shunt active filters based on current controlled PWM converters are seen as viable solution. The techniques that are used to generate desired compensating current are based on instantaneous extraction of compensating commands from the distorted currents or voltage signals in time domain. Time domain compensation has fast response, easy implementation and less computation burden compared to frequency domain.

Most of the active filters developed are based on sensing harmonics and reactive volt-ampere requirements of the non-linear load and require complex control. In some active filters, both phase voltages and load currents are transformed into the α-β orthogonal quantities, from which the instantaneous real and reactive power. The compensating currents are calculated from load currents and instantaneous powers. The harmonic components of power are calculated using high pass filters in the calculation circuit. The control circuit of the dc capacitor voltage regulates the average value of the voltage to the reference value. Reactive power compensation is achieved without sensing and computing the reactive current component of the load, thus simplifying the control circuit. Current control is achieved with constant switching frequency producing a better switching pattern. An active filter based on the instantaneous active and reactive current component in which current harmonics of positive and negative sequence including the fundamental current of negative sequence can be compensated. The system therefore acts as a harmonic and unbalanced current compensator. A comparison between the instantaneous active and reactive current component - method and the instantaneous active and reactive power method is realized. The instantaneous imaginary power was on the same basis as the conventional instantaneous real power in three-phase circuits. The instantaneous reactive power was defined, and the physical meaning was discussed in detail. The instantaneous reactive power compensator comprising switching devices, which requires practically no energy storage components, was proposed, according to the theory of the instantaneous reactive power[1].The voltage controlled inverter (VSI) based shunt active power filters has been used in recent year and recognized as a viable solution[2,3].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. The performance of *a* fuzzy logic controlled shunt active power filter has been studied and compared with conventional P1 controller[4].A new reactive volt–ampere compensator and harmonic suppressor system is proposed for low- and medium-power applications. The proposed technique makes the compensation process instantaneous. This feature is achieved using simplified control technique thereby enhancing the system reliability [5].A new control scheme for a parallel 3-phase active filter to eliminate harmonics and to compensate the reactive power of the non-linear loads. A 3-phase voltage source inverter bridge with a dc bus capacitor is used as an active filter (AF). A hysteresis based carrier less PWM current control is employed to derive the switching signals to the AF. Source reference currents are derived using load currents, dc bus voltage and source voltage [6]. Conventional PI and proportional integral derivative (PID) controllers have been used to estimate the peak reference currents and control the dc side capacitor voltage of the inverter. Most of the active filter systems use PI controller for maintaining the dc side capacitor voltage [7-13].

BASIC COMPENSATION PRINCIPLE

Figure 1 shows the basic compensation principle of a shunt active power filter. It is controlled to draw / supply a compensating current i_c from to the utility, so that it cancels current harmonics on the AC side, and makes the source current in phase with the source voltage. Figure 2 shows the different waveforms. Curve A is the load current waveform and curve B is the desired mains current. Curve C shows the compensating current injected by the active filter containing all the harmonics, to make mains current sinusoidal.

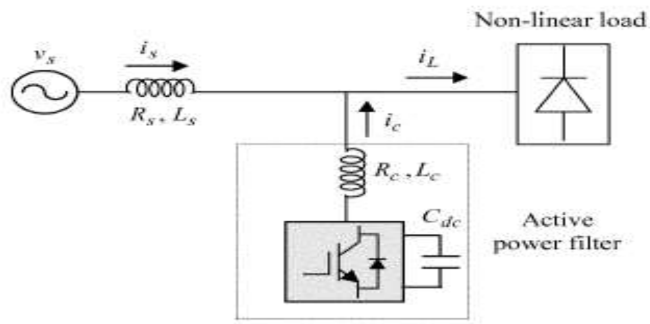

Figure 1Shunt active power filter Basic compensation principle.

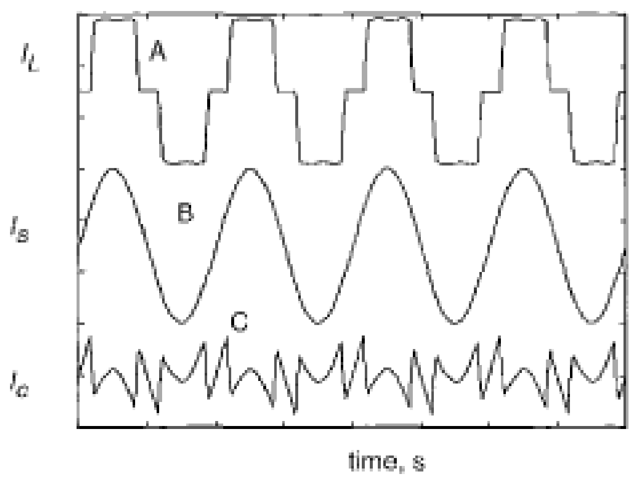

Figure 2 Shunt active power filter-Shapes of load, source and desired filter current wave forms.

ESTIMATION OF REFERENCE SOURCE CURRENT

From Figure 1, the instantaneous currents can be written a

$$i_s(t) = i_l(t) - i_c(t) \quad (1)$$

Source voltage is given by

$$v_s(t) = v_m \sin \omega t \quad (2)$$

If a non-linear load is applied, then the load current will have a fundamental component and harmonic components which can be represented as $i_L(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \emptyset_n)$

$$= I_1 \sin(\omega t + \emptyset_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \emptyset_n) \quad (3)$$

The instantaneous load power can be given as

$$P_L(t) = v_s(t) * i_L(t)$$

$$= V_m I_1 sin^2\omega t^* cos\emptyset_1 + V_m I_1 sin\omega t * cos\omega t * sin\emptyset_1 + V_m sin\omega t * \sum_{n=2}^{\infty} I_n \sin(n\omega t + \emptyset_n) \quad (4)$$

$$= P_f(t) + P_r(t) + P_h(t) \quad (5)$$

From (4), the real (fundamental) power drawn by the load is

$$P_f(t) = V_m I_1 sin^2\omega t^* cos\emptyset_1 = v_s(t) * i_s(t) \quad (6)$$

From (6), the source current supplied by the source, after compensation is

$$i_s(t) = \frac{P_f(t)}{v_s(t)} = I_1 cos\emptyset_1 sin\omega t = I_m sin\omega t$$

Where $I_{sm} = I_1 \cos \Phi_1$

There are also some switching losses in the PWM converter, and hence the utility must supply a small overhead for the capacitor leakage and converter switching losses in addition to the real power of the load. The total peak current supplied by the source is therefore

$$I_{sp} = I_{sm} + I_{sl} \quad (7)$$

Where I_{sl} is the peak value of loss current

If the active filter provides the total reactive and harmonic power, then $i_s(t)$ will be in phase with the utility voltage and purely sinusoidal. At this time, the active filter must provide the following compensation current

$$i_c(t) = i_l(t) - i_s(t)$$

Hence, for accurate and instantaneous compensation of reactive and harmonic power it is necessary to estimate, i.e. the fundamental component of the load current *as* the reference current.The peak value of the reference current I_{sp} can be estimated by controlling the DC side capacitor voltage. Ideal compensation requires the mains current to be sinusoidal and in phase with the source voltage, irrespective of the load current nature. The desired source currents, after compensation, can be given as

$$i_{sa}^* = I_{sp} \sin \omega t$$

$$i_{sb}^* = I_{sp} \sin(\omega t - 120^0)$$

$$i_{sc}^* = I_{sp} \sin(\omega t + 120^0)$$

Where $I_{sp} = (I_1 \cos\Phi_1 + I_{sl})$ the amplitude of the desired source current, while the phase angle can be obtained from the source voltages. Hence, the waveform and phases of the source currents are known, and only the magnitudes of the source currents need to be determined. This peak value of the reference current has been estimated by regulating the DC side capacitor voltage of the PWM converter. This capacitor voltage is compared with a reference value and the error is processed in a fuzzy controller. The output of the fuzzy controller has been considered as the amplitude of the desired source current, and the reference currents are estimated by multiplying this peak value with unit sine vectors in phase with the source voltages.

PI Control Scheme

The complete schematic diagram of the shunt active power filter is shown in figure 3 while figure 4 gives the control scheme realization. The actual capacitor voltage is compared with a set reference value. The error signal is fed to PI controller. The output of PI controller has been considered as peak value of the reference current. It is further multiplied by the unit sine vectors (u_{sa}, u_{sb}, and u_{sc}) in phase with the source voltages to obtain the reference currents (i_{sa}^*, i_{sb}^*, and i_{sc}^*). These reference currents and actual currents are given to a hysteresis based, carrierless PWM current controller to generate switching signals of the PWM converter. The difference of reference current template and actual current decides the operation of switches. To increase current of particular phase, the

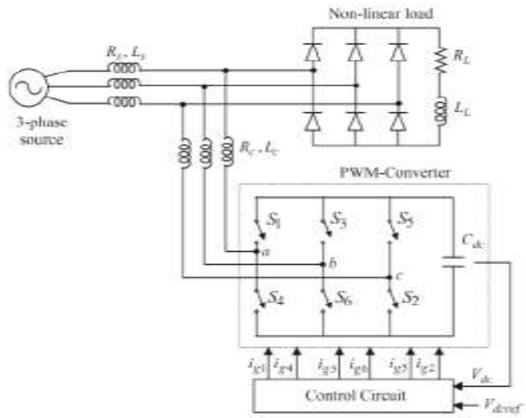

Figure 3 Schematic diagram of shunt active filter.

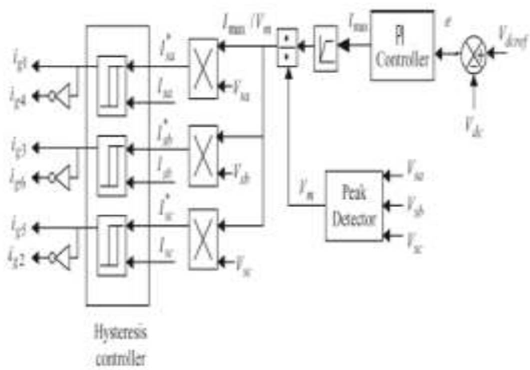

Figure 4 APF Control scheme with PI controller.

lower switch of the PWM converter of that particular phase is switched on, while to decrease the current the upper switch of the particular phase is switched on. These switching signals after proper isolation and amplification are given to the switching devices. Due to these switching actions current flows through the filter inductor L_c, to compensate the harmonic current and reactive power of the load, so that only active power drawn from the source.

SIMULATION

The system parameters selected for the simulation studies are as in Table I.A highly nonlinear load is considered for load compensation. The THD in the source current 28.05% . The compensator is switched on at t=0.05s and the integral time square error (ITSE) performance index is used for optimizing K_p and K_i coefficients of PI controller as 0.2 and9.32 respectively.

Table I

System parameters	Values
Source voltage(V_s)	100V
System frequency (f)	50 Hz
Source impedance (R_s, L_s)	0.1 Ω,0.15 mH
Filter impedance (R_c, L_c)	0.1 Ω,0.66 mH
Load impedance (R_L, L_L)	10 Ω,20 mH
Reference DC link voltage(V_{dcref})	220 V
DC link capacitance(C_{dc})	2400μF

The performance of PI controller is investigated thus the simulation results are as follows,

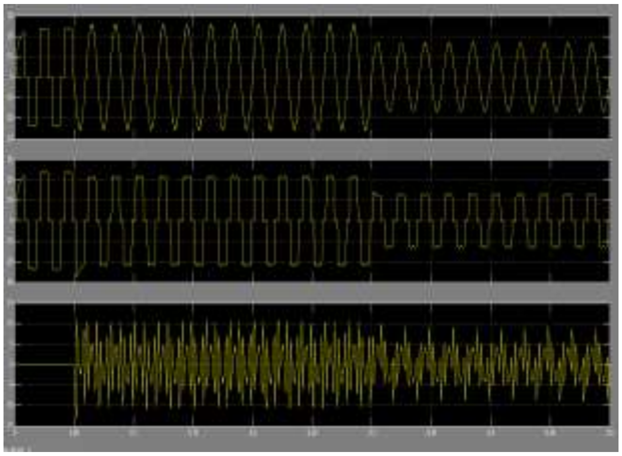

Figure 5 a) source current b) load current c) compensation current

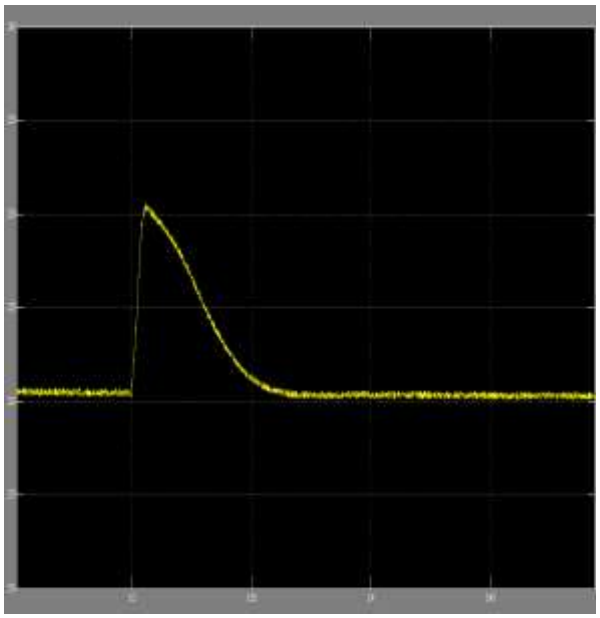

Figure 6 DC capacitor voltages

The settling time required for PI controller is 12 cycles approximately. Hence from result it can seen that the dc voltage deep is very high and it takes more cycles to settle down and THD in source current can reduce to normal value in 3-4 cycles.

CONCLUSION

A PI controlled shunt active power filter has been developed to improve the performance of controller for load compensation. The harmonic elimination process is simple and implemented by sensing the line currents only. The settling time required for PI controller is 12 cycles and source current THD is reduce to 3.44. The THD of source current after compensation is well below permissible limit of 5% that is in compliance with IEEE-519 standards harmonics.

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