Modeling of shunt active power filter using PSCAD/EMTDC

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Abstract

In this paper, a shunt active power filter (SAPF) has been used to eliminate the harmonic distortion and to improve the power quality of three-phase grid-connected power conditioning system (PCS). The adopted control strategy in active power filter system is based on the instantaneous reactive power theory (P-Q theory). Based on the theoretical analysis, the overall system of three-phase grid-connected with non-linear load PCS has been built and modeled using PSCAD®/EMTDC™. The simulation results are shown to verify the high effective performance of the implemented SAPF in power system and to verify the reasonableness of the system structure.

1. Introduction

Power quality is important factor of an electrical power system evaluation because it means to maintain the sinusoidal current waveform in phase with sinusoidal voltage waveform. The electric power quality is reduced because of current and voltage harmonics due to the application of power electric converters, the use of non-linear loads, reactive power etc…

Custom power devices are power conditioning equipments using static power electronic converters to improve the power quality of distribution system customers. These include dynamic voltage restorer (DVR)[1-3], unified power quality conditioner (UPQC)[4-5] and shunt active power filter (SAPF)[6-8].

DVR is a series compensator used to eliminate the disturbances in voltage and UPQC, which consists of both shunt and series compensators, is proposed as a one shot solution for power quality problems.

Conventionally, SAPF acts to eliminate the reactive power and harmonic currents produced by non-linear loads from the grid current by injecting compensating currents intended to results in sinusoidal grid current with unity power factor. Depending on the control theory and the inverter topology, SAPF is capable of compensating harmonic currents, power factor and unbalance of nonlinear loads

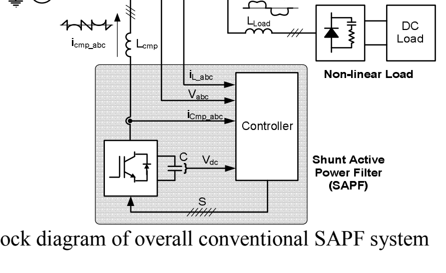

Fig.1 Block diagram of overall conventional SAPF system

In this paper, a SAPF has been adopted for power active conditioner of three-phase grid-connected power conditioning system (PCS). Based on the instantaneous reactive power theory (P-Q theory) and synchronous PI controller based control scheme, the overall SPAF system has been built and simulated by using PSCAD®/EMTDC™ tool. To simplify the analysis, the average PWM model is implemented for generating the inverter voltages. The simulation results are shown to verify the effectiveness of adopted control scheme.

Fig. 1 shows the block diagram of overall conventional SAPF system.

2. P-Q Theory

The P-Q theory[9] implements a transformation from a stationary reference system in abc coordinates, to a system with αβ coordinates. It corresponds to an algebraic transformation, known as Clarke transformation, which also produces a stationary reference system, where αβ coordinates are orthogonal to each other.

The voltages and currents in αβ coordinates are calculated as follows:

$$\begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} = T \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \qquad (1)$$

where - X can be voltage (V) or current (I)

$$\text{and} \quad T = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \qquad (2)$$

The P-Q theory power components are then calculated from voltages and currents in the αβ coordinates. Each component can be separated in its average and oscillating values.

2.1. Instantaneous Real Power (P)

$$P = V_\alpha I_\alpha + V_\beta I_\beta = \overline{P} + \widetilde{P} \qquad (3)$$

$\overline{P}$ is average value of the instantaneous real power. It corresponds to the energy per time unity that is transferred from the power source to the load, in a balanced way, through the abc coordinates (it is, indeed, the only desired power component to be supplied by the power source).

$\widetilde{P}$ is oscillating value of the instantaneous real power. It is the energy per time unity that is exchanged between the power source and the load, through the abc coordinates. Since $\widetilde{P}$ does not involve any energy transference from the power source to load, it must be compensated.

2.2. Instantaneous Imaginary Power (Q)

$$Q = V_\beta I_\alpha - V_\alpha I_\beta = \overline{Q} + \widetilde{Q} \tag{4}$$

$\overline{Q}$ is average value of instantaneous imaginary power.

$\widetilde{Q}$ is oscillating value of instantaneous imaginary power.

The instantaneous imaginary power, Q, has to do with power (and corresponding undesirable currents) that is exchanged between the system phases, and which does not imply any transference or exchange of energy between the power source and the load.

2.3. Compensating Power Selection

All undesirable power components generated by non-linear loads that can damage or make the power system overloaded. In this way, it would be desirable for a three-phase balanced-power-generating system to supply only the average real power $\overline{P}$ of the load. Thus, all other power components required by the non-linear load ($\widetilde{P}$, $\overline{Q}$, $\widetilde{Q}$) should be compensated by shunt compensator to make the three-phase instantaneous power to be constant and to minimize the power system currents. And the compensator should be controlled to compensate the oscillating real power $\widetilde{P}$ and the imaginary power $Q = \overline{Q} + \widetilde{Q}$. The compensation of the P-Q theory undesired power components ($\widetilde{P}$ and Q) can be accomplished with the use of an active power filter. The dynamic response of this active filter will depend on the time interval required by its control system to calculate these values.

The compensating currents can be calculated as:

$$\begin{bmatrix} I_{compa} \\ I_{comp\beta} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} -\widetilde{P} \\ -Q \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} = T^{-1} \begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} \tag{6}$$

where - X can be voltage (V) or current (I)

$$\text{and} \quad T^{-1} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{bmatrix} \tag{7}$$

The reason for adding a "-" sign to the oscillating value of instantaneous real power is to match them with the current direction.

3. Shunt Active Power Filter Topology

In Fig.1, the conventional SAPF uses the detailed switching PWM model. It comprises a PWM inverter with IGBTs which commutate at a switching frequency of 10kHz. In such a configuration, simulating the inverter requires calculation of commutation pulse with a very small time step, around 1μs. This gives considerably low simulation speed and quickly becomes prohibitive when the phenomena to be simulated have to last a few periods of the fundamental frequency (f_0=60Hz).

In order to shorten the simulation time, an average model was adopted as shown in Fig. 2. The principle of which consists in "eliminating" the PWM commutations.

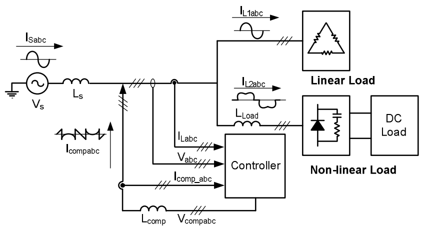

Fig.2 Block diagram of overall implemented SAPF system

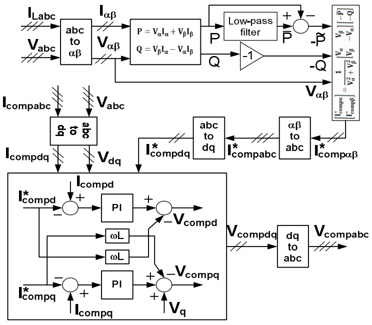

Fig. 3 ASPF current-controlled voltage control using average model

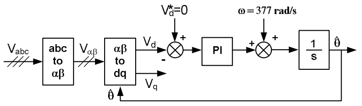

Fig. 4 Conventional PLL technique

Fig. 3 shows the current-controlled based compensating voltages generation. The average model generates the compensating voltages by using synchronous PI controller based current control scheme with decoupling technique.

The conventional phase-locked loop (PLL) was adopted as shown in Fig. 4.

4. Simulation

Fig. 5 shows an example of three-phase grid connected power conditioner performed by a SAPF with control system based on instantaneous P-Q theory using PSCAD/EMTDC. The system has 10kW linear load and 20kW non-linear load.

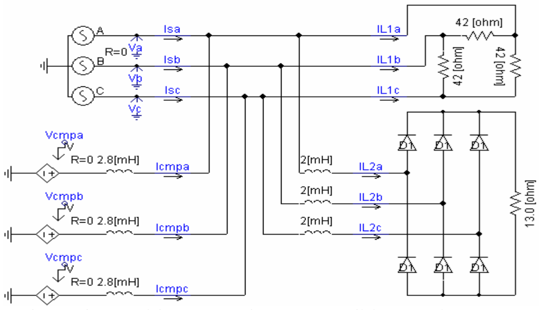

Fig. 5 Three-phase grid connected power conditioner using SAPF

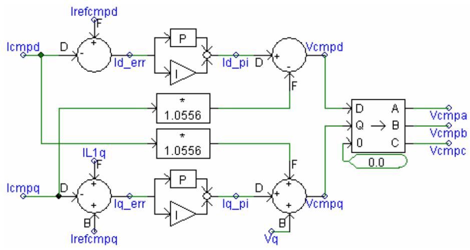

Fig. 6 Average model based compensating voltages generation

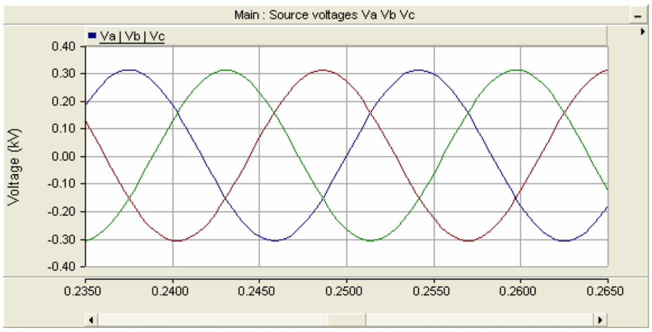

Fig. 7 Source voltages

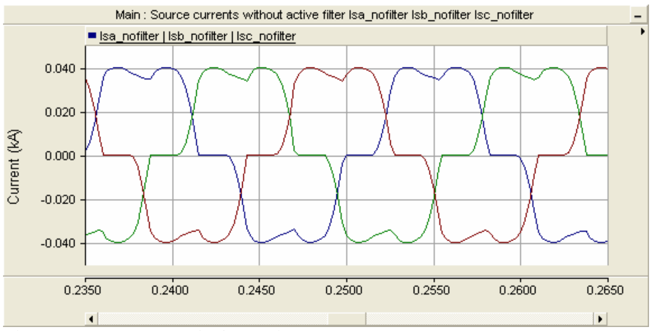

Fig. 8 Source currents before using SAPF

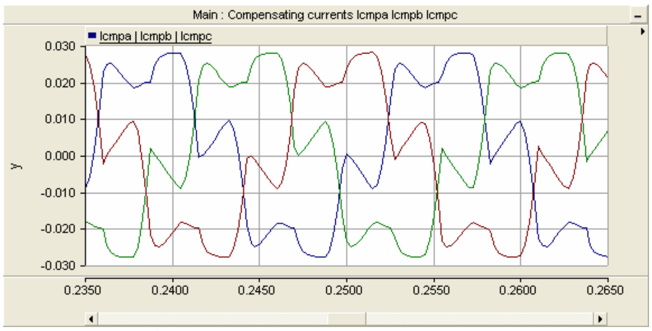

Fig. 9 Compensating currents

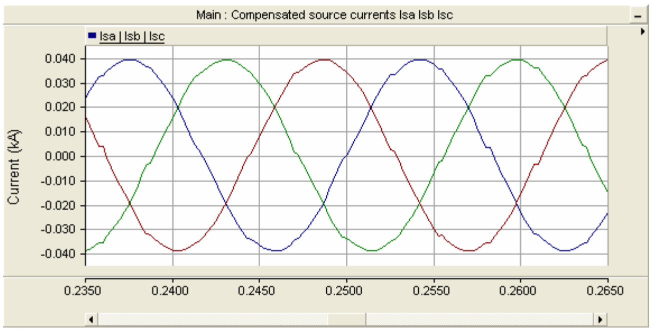

Fig. 10 Source currents after using SAPF

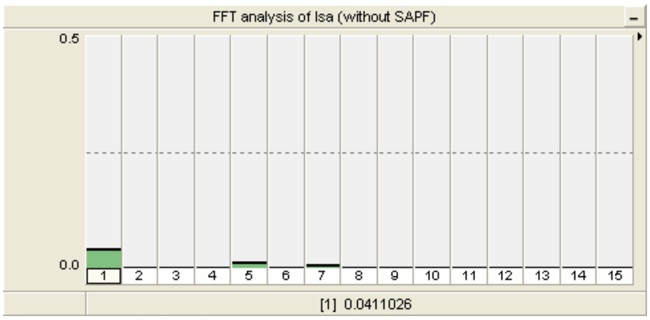

Fig. 11 FFT analysis of source currents after using SAPF

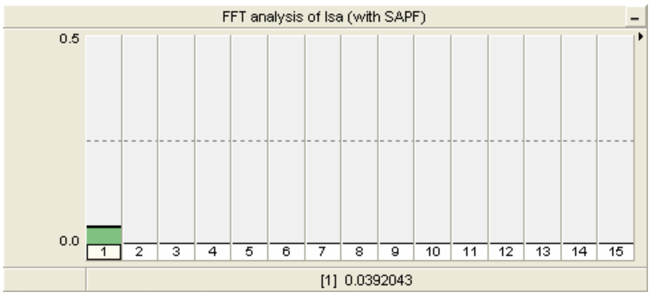

Fig. 12 FFT analysis of source currents after using SAPF

Fig. 6 shows the simulation model of current–controlled based compensating voltage control generation with average model

The simulation results are shown in Fig. 7 – Fig. 12. Where the source voltages are shown in Fig. 7 and the source currents without using SAPF are shown in Fig. 8. By using the compensating currents as shown in Fig. 9, we can compensate the source currents to be sinusoidal as shown in Fig. 10. Fig. 11 and Fig. 12 show the FFT analysis of source current (phase a) before and after using SAPF, respectively.

5. Conclusions

This paper shows that it is possible to associate the SAPF in parallel in order to compensate currents on a given electric installation. The importance of a fast response for the active filter control system is commended. Besides the improvement of the dynamic response of the filter, it can also contribute to a reduction in its cost, since the active filter capacitor can be eliminated by using the average model. Based on the theoretical analysis, the experiment will be carried out.

Reference

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