ANALYSIS AND SIMULATION OF A PARALLEL ACTIVE POWER FILTER FOR THREE PHASE SYSTEMS WITH 12 PULSE LOAD

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ABSTRACT

The aim of this paper is to analyze a parallel active power filter (APF) operating in the industry and simulate a computer-based modeling of that system. A control strategy based on the p-q method, for detecting harmonics are described. Some data, which were measured from the parallel APF operating in network, are given. A APF computer-based model is developed and simulated. Finally, experimental results and simulation results are evaluated.

I. INTRODUCTION

Conventiol LC passive filters have been used to eleminate the harmonics in energy systems and to correct the power factor of load. But in practice, these filters have following disadvantages[7],

- The characteristic of filter is affected by load impedance
- The filter capasitor is determined in terms of both fundamental and harmonic component of current.
- The filter is overloaded when harmonic current component increases.
- They may cause an increase in the harmonic currents on the load side by generating parallel rezonance at a specific frequency between power system and filter components.
- They may cause a series rezonance with power system.

In order to solve that kind of problems, active power filters have been developed. In resent years, various type of active power filters and their control strategies have been presented in the literature.Active filter uses power electronic switching elements to generate harmonic currents to eleminate harmonic currents caused by a non-linear load. The approach is based on the principle of injecting harmonic current into the system with the same amplitude and in reverse phase to that of the load current harmonic[1]-[10].

Generally, Active filters are used in the elemination of current and voltage harmonics as well as in the reactive power compansation and supply voltage regulation. Active power filters can reduce current harmonics produced by non-linear loads and draw or generate reactive power .When they are compared to passive filters, main disadvantage of them are high cost of investment.

II. ACTIVE POWER FILTER

Two types of active filter are present, series and parallel[5],[6],[8],[9]. Parallel Filters operate in parallel to the system. The approach is based on the principle of injecting harmonic current to ac system with the same amplitude and in reverse phase to that of the load current harmonics. Parallel active filters are effective for loads which can be considered especially as current-source type of harmonic sources[10]. Basic principle of parallel active filter for a harmonic current source is illustrated in Figure 1.

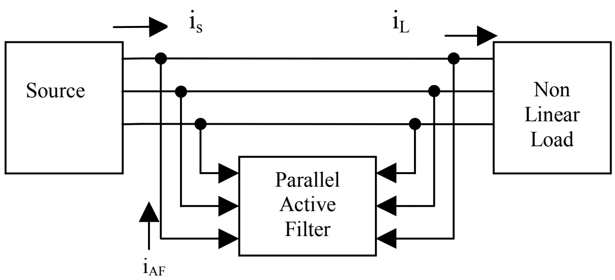


Fig.1. Basic parallel active power filter configuration

III. PROPOSED CONTROL STRATEGY

In the literature for the first time,H. Akagi et al. proposed "The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits" (also known as instantaneous power theory, or p-q theory) in 1983. It was based on instantaneous values in three-phase power systems with or without neutral wire, and was valid for steady-state or transient operations. The p-q theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the a-b-c coordinates to the α-β-0 coordinates, followed by the calculation of the p-q theory instantaneous power components.

In instantaneous power theory, it is not necessary to determine load current harmonics seperately. Transformation of the three phase current and voltage expressions into α-β coordinates is given by following equations[1],

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

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

In three phase systems, conventional instantaneous is defined as,

$$p = V_\alpha \times i_\alpha + V_\beta \times i_\beta \quad (3)$$

Where p is equal to usual equation($p=V_a \times i_a+V_b \times i_b+V_c \times i_c$). Akagi expresses the instantaneous imaginary space power vector to define instantaneous reactive power as following,

$$q = \vec{V}_\alpha \times \dot{i}_\beta + \vec{V}_\beta \times \dot{i}_\alpha \quad (4)$$

In Equation (4), space vector is imaginary axis vector and is perpendicular to real axis in α-β coordinates.When it is considered that V_α to i_α, V_β to i_β are parallel and V_α to i_β, V_β to i_α are perpendicular, conventional instantaneous power and instantaneous imaginary power are defined as following,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (5)$$

In equation (5), $V_\alpha \times i_\alpha$ and $V_\beta \times i_\beta$ mean instantaneous power since these terms consist of instantaneous current and voltage in the same axis frame.In contrast, $V_\alpha \times i_\beta$ and $V_\beta \times i_\alpha$ aren't instantaneous real power because of not having same axis frame[1],[2].

It is different the meaning of instantaneous imaginary power in three phase systems from that in each a phase. The physical meaning of p and q was already discussed in detail in[1].The imaginary instantaneous power and real instantaneous power are divided into two section as direct component (DC) and alternating component (AC)[4].

$$p = \overline{p} + \tilde{p} \quad (6)$$

$$q = \overline{q} + \tilde{q} \quad (7)$$

The physical meanings of these quantities can be given as follows[9],

$\overline{p}$ = direct component of p associated with the fundemental frequency active component of load current

$\tilde{p}$ = alternating component of p associated with the harmonic active components of load current.

$\overline{q}$ = direct component of p associated with the fundemental frequency reactive component of load current

$\tilde{q}$ = alternating component of p associated with the harmonic reactive components of load current.

If we want to compansate both the power drawn by load and harmonics,only $\overline{p}$ will be power component required by the p-q theory[6].If expression (5) is inverted,the referance filter currents can be obtained as follows,

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} \\ -q \end{bmatrix} \quad (8)$$

In order to obtain the reference compensation currents in the a-b-c coordinates,the inverse of the transformation given in expression (2) is applied and the reference filter currents are determined.

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{ca}^* \\ i_{c\beta}^* \end{bmatrix} \quad (9)$$

The control block diagram of this method for a system with three phase and without neutral wire is illustrated in Figure 2.To seperate the variable and stationary sections of p and q powers, a low-pass Butterworth filter is used.

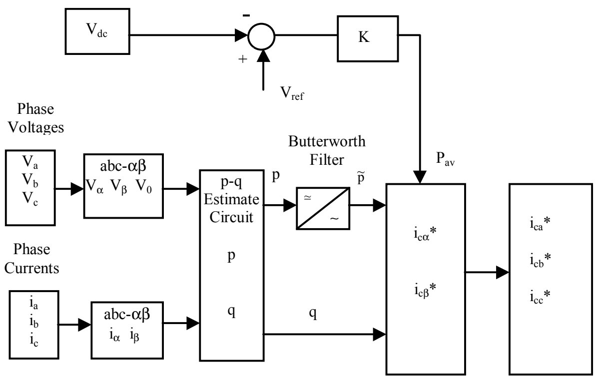


Fig.2. Control block diagram

IV. IMPLEMENTATION AND SIMULATION

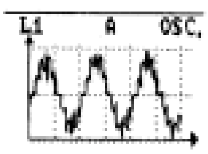
The data were taken from an active filter connected to UPS having 80 kVA power with three-phase and 12 pulse in the industry. To measure harmonic values, a harmonic analyzer which operates at 25 kHz and can measure up to 25^{th} harmonic order was used. The measurements with and without filter were taken by this device connected to the mains in the entrence of UPS.The Active Filter was operated in both harmonic and reactive power mode. The current and voltage values of each phase drawn by the energy system were shown in Table I, II, III and their wave shapes were illustrated in Figure 3,4,5.

Harmonic Order	Phase1/Phase2/Phase3	
	V=217.3/217.5/218. I=125/125/116 PF=0.756/0.752/0.777	
	P=20/20/19 kW Q=15/15/14kVAr S=27/27/25 kVA	
	Voltages (V)	Currents (I)
1	217.0/217.2/218.2	118\118\110
2	1.2/1.2/0.7	2\2\1
3	0.3/0.9/0.8	2\2\0
4	0.3/0.2/0.1	0\1\1
5	1.0/0.8/0.7	3\3\4
7	0.5/0.6/0.5	3\3\1
10	0.3/0.2/0.3	0\0\1
11	3.5/3.3/3.1	28\28\25
12	0.5/0.2/0.0	1\1\0
13	2.5/2.5/2.6	16\16\16
14	0.2/0.3/0.1	0\0\1
15	0.7/0.6/1.0	0\0\1
23	1.7/0.1/1.4	4\4\4
25	0.9/0.9/1.6	3\3\3

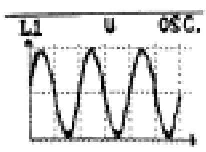
Table I.The measured quantities without filter

Harmonic Order	Phase1/Phase2/Phase3	
	V=210.6/214/213.6 I=130/117/125 PF=0.789/0.824/0.804	
	P=21/20/25 kW Q=16/13/15kVAr S=27/21/26kVA	
	THDU=1.6/1.3/1.2 THDI=10.9 50Hz	
	Voltages (V)	Currents (A)
1	206.4/212/210.3	126115/122
2	4.4/5.1/5.1	5/3/5
3	3.6/3.3/1.9	0/0/1
4	1.1/1.5/0.3	0/1/1
5	0.0/1.3/1.4	3/1/2
6	1.4/1.2/0.6	0/1/1
7	0.7/1.0/0.4	1/1/0
9	1.0/0.3/1.1	0/0/1
10	1.2/0.8/0.2	0/1/1
11	0.9/0.6/0.2	3/3/2
12	0.5/0.7/0.3	2/2/1
13	1.3/0.8/0.9	4/5/5
14	0.2/0.3/0.9	0/0/1
15	0.6/0.0/1.2	1/0/0
17	0.2/0.5/0.2	1/0/1
19	0.1/0.5/0.2	1/2/1
23	0.0/0.4/0.9	1/1/1
25	0.3/0.3/0.3	0/1/0

Table II.The measured quantities with active filter in harmonic mode



126	RMS	Peaks
29.1%	THD	+224
50.0	Hz	-231
0.754	PF	

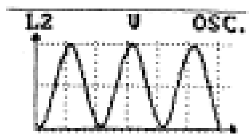


217.3	RMS	Peaks
2.2%	THD	+307.1
50.0	Hz	-309.3
0.755	PF	

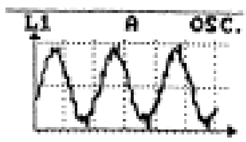
Fig.3 Load current and phase-neutre voltage without filter

Harmonic Order	Phase1/Phase2/Phase3	
	V=205.6/206.4/206.6 I=112/99/104 PF=0.979/0.978/0.979	
	P=22/20/20 kW Q=1/1/1kVAr S=23/21/21kVA	
	THDU=1.5/1.4/1.4 THDI=14/14.9/15.1 50Hz	
	Voltages (V)	Currents (I)
1	205.2/205.8/206.5	110/97/102
2	1.5/1/1.4	0/2/2
4	0.6/0.1/0	1/2/1
5	1.3/1/0.6	4/4/4
6	0.5/0.2/0.4	1/0/0
7	0.9/0.5/0.8	3/2/3
8	0.4/0.1/0.1	1/0/1
9	0.6/0.8/1.6	0/0/1
11	0.5/0.5/0.3	10/0/9
13	1.0/1.1/1.2	7/7/8
17	0.4/0.4/0.3	1/0/0
19	0.5/0.6/0.4	1/0/1
23	0.1/0.6/0.3	0/1/1
25	0.4/0.2/0.2	1/0/1

Table III.The measured quantities with active filter in reactive power mode

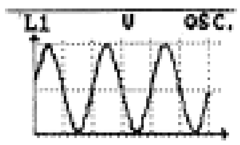


209.9	RMS	Peaks
1.3%	THD	+302.9
50.0	Hz	-303.4
0.836	PF	

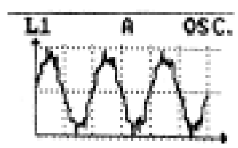


129	RMS	Peaks
9.4%	THD	+217
50.0	Hz	-213
0.007	PF	

Fig. 4 The load current and source voltage with active filter in harmonic mode



203.5	RMS	Peaks
1.4%	THD	+298.2
50.0	Hz	-284.8
0.98	PF	



111	RMS	Peaks
14.5%	THD	+186
50.0	Hz	-184
0.98	PF	

Fig. 5.The load current and source voltage with active filter in reactive power mode

V. SYSTEM MODEL

The active filter model resembling operating system was built in Matlab Simulink 4.0. Two three-phase rectifiers that were connected to circuit in series through a transformer whose secondary windings were connected as star and delta were used and RL load was taken into account.The changes of drawn currents were shown in Fig. 7 and parameters of circuit were shown in Table IV.

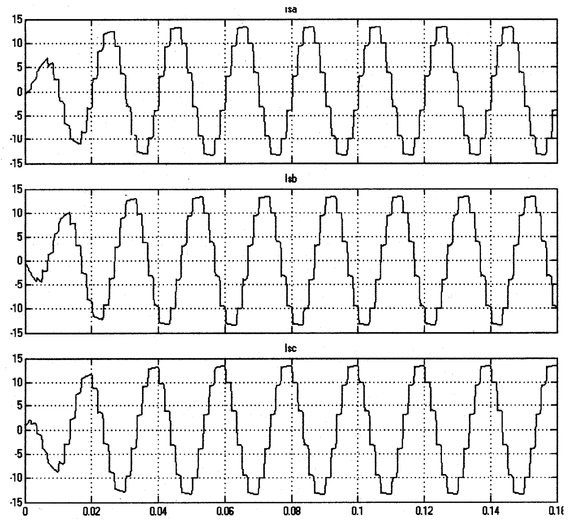


Fig 7 Phase currents drawn by rectifier with 12 pulse

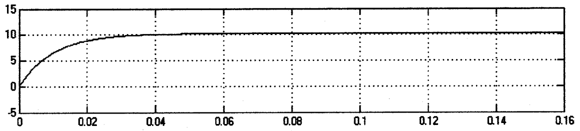


Fig 8 The load current

$V_a = 380$ V	$V_{dc} = 700$ V
$L_h = 500$ µH	$L_f = 10$ mH
$R_{load} = 10\ \Omega$ $L_{load} = 1$ H	The used element in filter: IGBT
Transformer: 135 kVA,380/220 V f = 50 Hz	$f_T = 1080$ Hz

Table IV. The circuit parameters

The delta wave method was used in the developed shunt active filter model.In addition,a second order low-pass Butterworth filter having 300 Hz cutoff frequency was used to seperate AC, DC components defined in the p-q algorithm.The changes of current injected by active filter are illustrared in Figure 9.Consequently, the changes of source currents are illustrared in Figure 10.

VI. CONCULUSION

It is concluded from this study that parallel active filter reduces supply current THD from 29.1% to 9.4 % and supply voltage THD from 2.2 % to 1.3 %. These values are under those determined by standarts. Besides, the measured values clearly show that parallel active filter increases power factor from 0.75 to 0.98 in reactive power compensation.

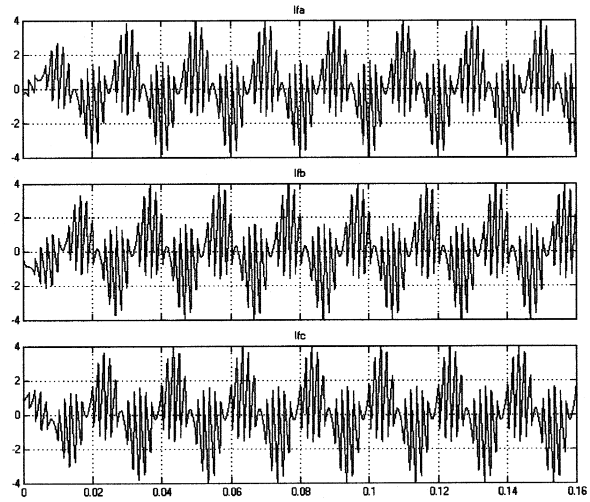


Fig. 9 The injected currents to each phase

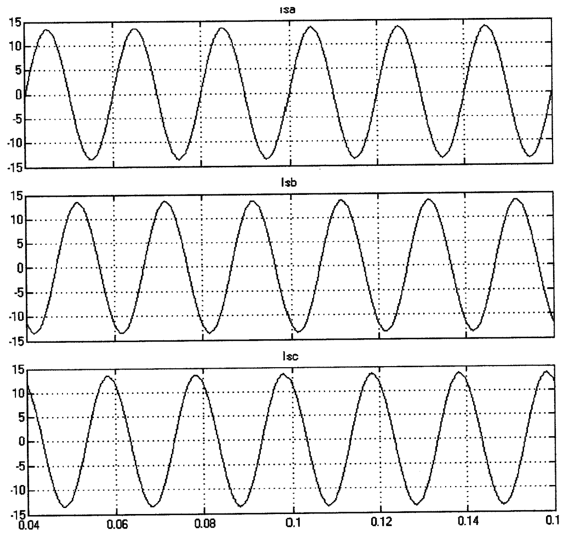


Fig 10. The load currents while active filter operates

Consequently, it has been shown that parallel active filter eleminates harmonics produced by a non-linear load. The presented control method has been verified with simulation results. This study shows that parallel active filter can have a wide application area in the industry to control harmonics generated by non-linear loads and also to compansate reactive power.

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