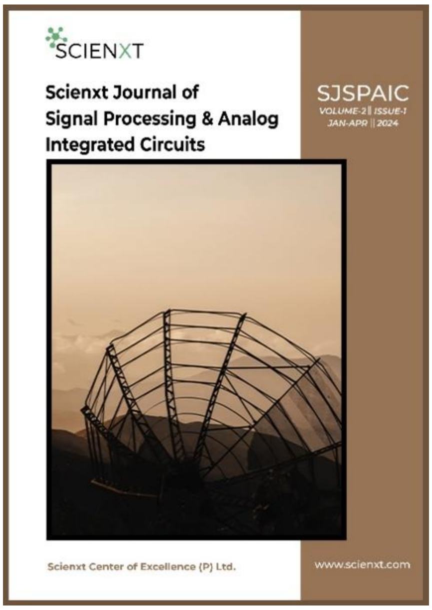

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3-Phase shunt active power filter-A review of current harmonic reduction techniques

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Abstract:

Shunt Active Power Filters represent the most important and commonly used filters in industrial purpose and for the reduction of current harmonics and improvement of the power factor in power systems with nonlinear loads, such as diode rectifiers. A pulse width modulation (PWM) power converter constitutes the main component of the APF , this is due not only to the fact that they eliminate the harmonic current with a neglected amount of active fundamental current supplied to compensate system losses, but also they are suitable for a wide range of power ratings. Modern power electronic devices such as IGBT allowed configuring non harmonic generating shunt APF. The aim of this paper highlight on this type of configuration namely the voltage source inverter based three phase shunt active power filters to present an overview on the mater.

Keywords:

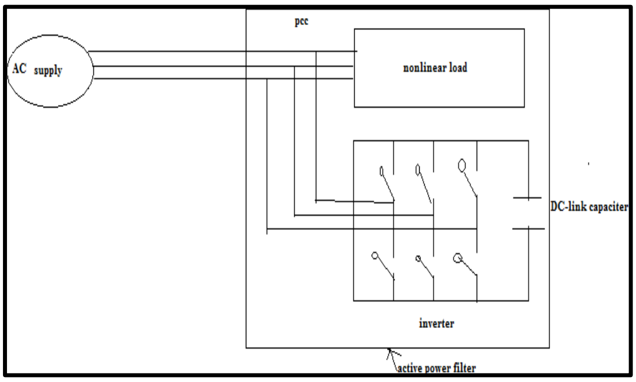
Inverter based shunt active power filter Power electronic devices, Pulse width Modulation

1. Introduction:

In the last two decades, power system conditioning circuits have known an important development resulted to two groups of circuits APF, the first group is represented by harmonic and the major part of the shunt APF is a voltage-source pulse width modulated (PWM) converter. The converter produces compensating currents, which neutralize the harmonic and reactive components of the load currents generating circuits used in reactive power compensation while the second one consists of non-harmonic generating circuits efficiently used not only in reactive power compensation but also to balance three phase systems and to cancel harmonic currents [1].The inverter based shunt active power filter is one of the active power line conditioners (APLC), which is configured by modern power semiconductor switches.

In this case the shunt APF use an inverter and a dc source to produce an equal but opposite compensating current to be injected to the network at the suitable point of common coupling (PCC) which provides more efficient and more economical components, encourages the interest in non-harmonic generation. This configuration in globes two types namely the voltage source inverter based shunt APF and the current source inverter based shunts APF the continuous improvement of semiconductor device technology.

Active power filter (APF) becomes increasingly popular in power systems with non-linear loads, such as rectifiers, replacing the traditional passive harmonic traps. Shunt APF, connected in parallel with the power line, are more common than the series ones, which require coupling transformers Whatever control method is employed, the compensating current generated in the fast-switching PWM converter carries significant amount of noise in the range beginning at the Switching frequency. In other words, although low-order harmonics of the line current are strongly attenuated, harmonic clusters related to the switching frequency are generated in their place.



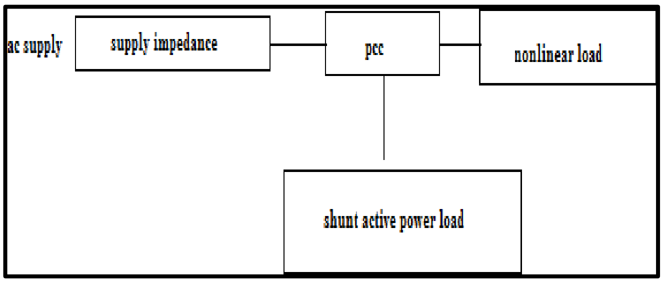


Figure. 1: Voltage source inverter based three-phase shunt active power filter

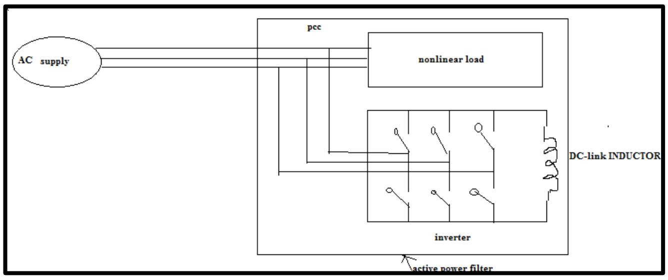


Figure. 2: Current source inverter based three-phase shunt active power filter

2. Inverters as shunt active power filters:

The principal parts of an inverter-based shunt APF are illustrated in figure 1 the first part is a smoothing coupling low pass filter which can be a first order (inductor) or a third order filter in case of a voltage source inverter (VSI) otherwise a second order filter (an inductor and a capacitor) in case of a current source inverter (CSI).

This filter allows the connection between the converter and the network. The second part is the converter, the third part represent the DC energy storage element, which can be either a capacitor for the VSI or an inductor for the CSI. Finally, the last part represents the control system of the APF, the role of which is to extract and control compensating current and regulate the current or voltage of the DC energy storage element In fact the VSI and CSI are similar in behaviour, the choice between the two configurations depends on several criterion namely the semiconductors used, the DC energy storage element, power ratings, control complexity.

The comparison between the two configurations presented in table II, show a significant advantageous aspect of the VSI compared to the CSI as shunt APF this can explain the dominance of the VSI based APF. In fact the VSI and CSI are similar in behaviour, the choice between the two configurations depends on several criterion namely the semiconductors used,

the DC energy storage element, power ratings, control The comparison between the two configurations presented in a significant advantageous aspect of the VSI compared to the CSI as shunt APF this can explain the Dominance of the VSI based APF.

Figure. 3: Basic principle of shunt active power filter

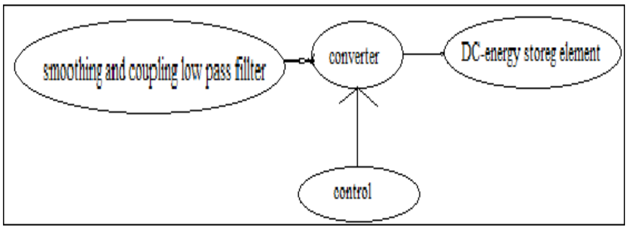


Figure. 4: Principal parts of an inverter-based shunt APF

The principal parts of an inverter based shunt APF are illustrated in figure, the first part is a smoothing coupling low pass filter which can be a first order (inductor) or a third order filter in case of a voltage source inverter (VSI) otherwise a second order filter (an inductor and a capacitor) in case of a current source inverter (CSI). This filter allows the connection between the converter and the network. The second part is the converter, the third part represent the DC energy storage element, which can be either a capacitor for the VSI or an inductor for the CSI. Finally, the last part represents the control system of the APF, the role of which is to extract and control compensating current and regulate the current or voltage of the DC energy storage element.

3. Analytic modelling of VSI as a three phase shunt APF:

The voltage source shunt active power filter (APF) is supposed to be connected to a balanced three-phase voltage source, with no zero-sequence in the currents. Applying Kirchhoff laws for the currents and the voltages at the connection point of the shunt APF leads to the following equations

$$\begin{cases} V_{sa}=R_f i_{fa}+L_f \dfrac{di_{fa}}{dt}+V_{fa}+V_{MN} \\ V_{sb}=R_f i_{fb}+L_f \dfrac{di_{fb}}{dt}+V_{fb}+V_{MN} \\ V_{sc}=R_f i_{fc}+L_f \dfrac{di_{fc}}{dt}+V_{fc}+V_{MN} \end{cases}$$ Equation. 1

The neutral-to-phase APF voltages are given

$$\begin{cases} V_{f1}=V_{fa}+V_{MN} \\ V_{f2}=V_{fb}+V_{MN} \\ V_{f3}=V_{fc}+V_{MN} \end{cases}$$ Equation. 2

Summing the three equations in (2) the masse-to neutral voltage is given by:

$$V_{MN} = -\frac{1}{3}(V_{fa} + V_{fb} + V_{fc})$$ Equation. 3

By substituting (3) in (2) one can obtain:

$$\begin{cases} V_{f1} = \frac{2}{3}V_{fa} - \frac{1}{3}V_{fb} - \frac{1}{3}V_{fc} \\ V_{f2} = -\frac{1}{3}V_{fa} + \frac{2}{3}V_{fb} - \frac{1}{3}V_{fc} \\ V_{f3} = -\frac{1}{3}V_{fa} - \frac{1}{3}V_{fb} + \frac{2}{3}V_{fc} \end{cases}$$ Equation. 4

The equations (4) can be written in a matrix form:

$$\begin{bmatrix} V_{f1} \\ V_{f2} \\ V_{f3} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} V_{fa} \\ V_{fb} \\ V_{fc} \end{bmatrix}$$ Equation 5

The voltages V f, V ft and V f, take the values 0 or +V d C depending on the switching function CK of the k inverter leg (k = 1, 2, 3), which is defined as, follows: Ck {=T ' if s k is on and sk +3 is off LO, if s k is off and sk +3 is on

$$\begin{bmatrix} V_{fa} \\ V_{fb} \\ V_{fc} \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} V_{dc}$$ Equation 6

$$\begin{bmatrix} V_{f1} \\ V_{f2} \\ V_{f3} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} V_{dc}$$ Equation…...7

By substituting (7) in (5) the neutral-to-phase voltages are expressed

$$\begin{bmatrix} d_{n1} \\ d_{n2} \\ d_{n3} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix}$$ Equation…...8

Using (8), the eight possible values of the voltages V1, V, 2 and V, 3 can be deduced in table I, note that n is the number of the switching states. Furthermore, a switching state function d n f k can be defined

$$\begin{bmatrix} V_{f1} \\ V_{f2} \\ V_{f3} \end{bmatrix} = \begin{bmatrix} d_{n1} \\ d_{n2} \\ d_{n3} \end{bmatrix} V_{d}$$ Equation...9

This allows obtaining the following relation:

$$\begin{cases} L_f \frac{di_{fa}}{dt} = -R_f i_{fa} - d_{n1} V_{dc} + V_{sa} \\ L_f \frac{di_{fb}}{dt} = -R_f i_{fb} - d_{n2} Vdc + V_{sb} \\ L_f \frac{di_{fc}}{dt} = -R_f i_{fc} - d_{n3} V_{dc} + V_{sc} \end{cases}$$

Equation...10

By substituting (10) in (1) and taking into account the relation

(2) the following equations hold by

$$\frac{dV_{dc}}{dt} = \frac{1}{C_{dc}} \left(2d_{n1} + d_{n2}\right) i_{fa} + \frac{1}{C_{dc}} \left(d_{n1} + 2d_{n2}\right) i_{fb}$$

Equation...11

On the dc side of the APF circuit the following equation holds

$$\begin{cases} L_f \frac{di_{fa}}{dt} = -R_f i_{fa} - d_{n1} V_{dc} + V_{sa} \\ L_f \frac{di_{fb}}{dt} = -R_f i_{fb} - d_{n2} V_{dc} + V_{sb} \\ \frac{dV_{dc}}{dt} = \frac{1}{C_{dc}} \left(2d_{n1} + d_{n2}\right) i_{fa} + \frac{1}{C_{dc}} \left(d_{n1} + 2d_{n2}\right) i_{fb} \end{cases}$$

Equation...12

Using the tow first equations in (11) and the relation (12) a (6) complete model of the APF in the 'a b c' frame is obtained by.

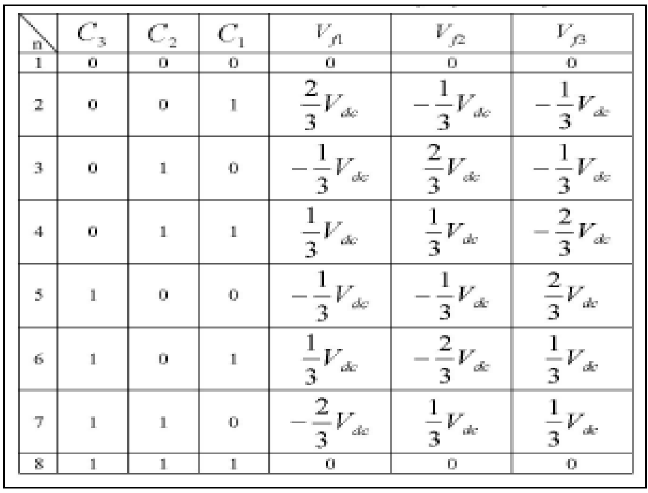
$$\begin{cases} L_f \frac{di_{fd}}{dt} = -R_f i_{fd} + L_f \omega \, i_{fq} - d_{nd} V_{dc} + V_{sd} \\ L_f \frac{di_{fq}}{dt} = -R_f i_{fq} - L_f \omega \, i_{fd} - d_{nq} V_{dc} + V_{sq} \\ C_{dc} \frac{dV_{dc}}{dt} = d_{nd} i_{fd} + d_{nq} i_{fq} \end{cases}$$

Equation...13

In fact the active power filter model can be obtained in the synchronous 'dq' frame rotating by the supply frequency, this model in equations (14), allows avoiding the effect of interaction between the phases and setting the positive sequence components at fundamental frequency to constant Values.

Dimension of the coupling element The inductor Lf assures the link between the source and the APF, as a first order passive filter the inductor prevent the Contamination of the system from the switching frequencies produced by the APF, consequently the inductance should be high; on the other hand and because of controllability reasons the inductance should be low. The choice of the appropriate value of Lf is then, nothing but a compromise between a high value and a low one. In fact a third order passive filter may efficiently satisfy this compromise, the main drawback of this solution is the increasing control complexity.

Table. 1: Possible values of voltages



n	C_3	C_2	C_1	V_{f1}	V_{f2}	V_{f3}
1	0	0	0	0	0	0
2	0	0	1	$\frac{2}{3}V_{dc}$	$-\frac{1}{3}V_{dc}$	$-\frac{1}{3}V_{dc}$
3	0	1	0	$-\frac{1}{3}V_{dc}$	$\frac{2}{3}V_{dc}$	$-\frac{1}{3}V_{dc}$
4	0	1	1	$\frac{1}{3}V_{dc}$	$\frac{1}{3}V_{dc}$	$-\frac{2}{3}V_{dc}$
5	1	0	0	$-\frac{1}{3}V_{dc}$	$-\frac{1}{3}V_{dc}$	$\frac{2}{3}V_{dc}$
6	1	0	1	$\frac{1}{3}V_{dc}$	$-\frac{2}{3}V_{dc}$	$\frac{1}{3}V_{dc}$
7	1	1	0	$-\frac{2}{3}V_{dc}$	$\frac{1}{3}V_{dc}$	$\frac{1}{3}V_{dc}$
8	1	1	1	0	0	0

Equitation...14

4. Dimension of the DC energy storage capacitor:

On the dc side of the APF, the energy storage element is a capacitor Cd, that supplies the dc voltage V d,. The quality of distortion compensation is affected by the choice of the energy storage element parameters, a high dc voltage V d, (high value of C d J) ameliorate the dynamics of the filter and minimize the voltage ripple in the capacitor.

The following relation can obtain the minimum value of C dc Choice of power electronic switches to be used in the converter The selection of semiconductors to be used to configure the VSI based APF depends on several parameters to be taken in account, namely power ratings, controllability, cost and performance of the equipments. In fact the distortion type detected in a power system has a great importance in the choice of power electronic devices. Nowadays, insulated gate bipolar transistors (IGBTs) are considered as ideal solid-state devices for APFs and many shunt active filters of PWM inverters using IGBTs are commercialized and operating properly. The IGBTs allow configuring PWM voltage source inverter based Multi- Functional APFs designed for cancelling current harmonics, power factor correction and voltage regulation.

5. Control strategies:

As already mentioned, the role of the control system of the voltage source APF is to extract compensation current references, control the generation of compensating currents and to regulate the dc voltage in the dc side. In the control scheme APF is presented.

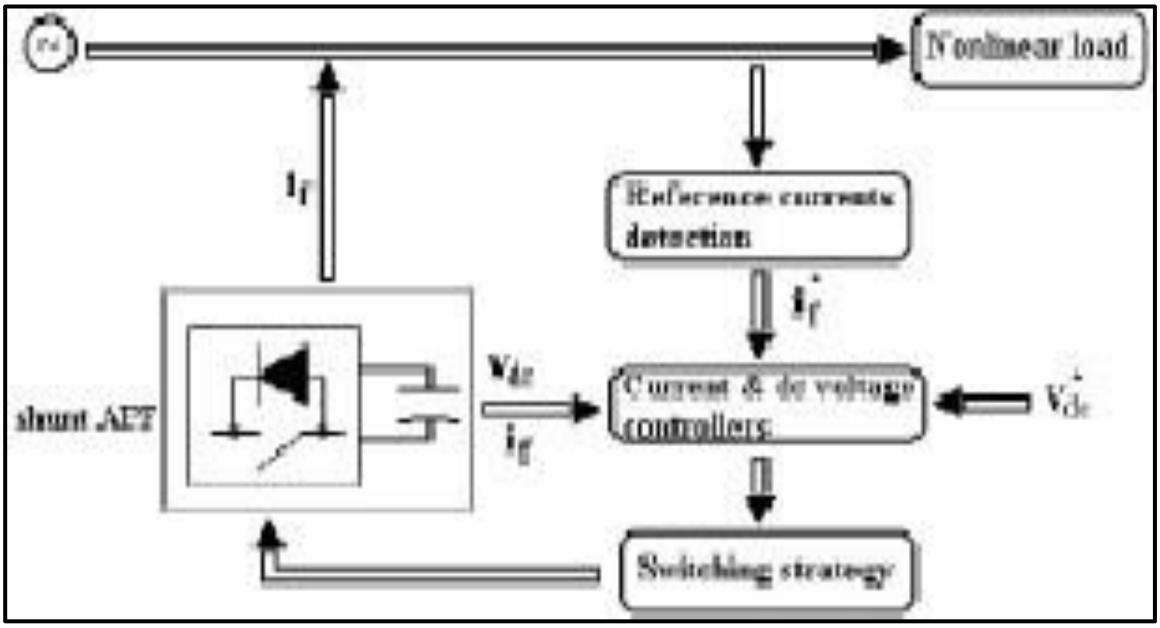


Figure. Control scheme of ashunt active power filter

6. Current/ voltage control techniques:

The increasing interest in power quality and low cost equipments to solve power distortion problems, lead to a great interest in applied control techniques to active power filters, in fact there is a tendency to explore the performance of intelligent control methods based on artificial intelligence namely neural networks and genetic algorithms in APFs current / voltage control. Based on a brief review of the literature dealing with comparison between different control techniques the table IV is presented.

Table. 2: Comparison of current controls techniques applied to vsi based three-phase shunt apf

Performance criteria	**PI controller**	**Sliding mode**	**Fuzzy Logic**	**Neural Network s**
THD of compensated line	Below 5%	Lower compared to PI	Below 5%	Lower compare d to PI
Transient Response	Acceptable	Better compared to PI	Better compared to PI	Excellent
Steady state response	Acceptable	Excellent	Comparable to PI	Good
Response speed	Acceptable	Fast	Fast compared to PI	Fast

7. Conclusion:

An overview on voltage source inverter-based shunt three phase active power filters was presented. The most common analytic models and compensating current reference detection methods successfully used in three-phase systems were stated. A brief significant literature based comparison of different current control techniques applied to this type of configuration was presented Shunt active power filters (APF) are commonly used for the reduction of current harmonics and improvement of the power factor in power systems with nonlinear loads, such as diode rectifiers. A pulse width modulation (PWM) power converter constitutes the main component of the APF. In fact then aim of this work was to highlight the main factors ensuring a successful application of VSI based shunt three phase active power filters.

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