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Hybrid power filter: A review

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Abstract
Large industrial non-linear loads have significant capacity to perturb the supply grid in terms of harmonic power and fundamental reactive power. In order to obtain a better performance than those of the conventional passive filter solutions, active power filters (APF) have been developed. For large power application, the ratings of active power filter as well as losses are increased. As a result, hybrid power filter which combine the advantages of both passive and active filters has been developed. In this paper the review of various hybrid active power filter topologies, detail study of design and control topologies of hybrid active power filter and their comparison is taken into consideration.

Keywords: Power quality Issues, Hybrid active power filter, APF in series with shunt PPF

1. Introduction

In recent years, advancement in power electronics devices has increased the usage of non-linear loads to greater extent. Widespread use of non-linear loads deteriorates the power quality in both transmission and distribution systems. The ideal power quality is defined by electrical power energy with pure sinusoidal supply voltage waveform at a constant frequency and a specified constant magnitude. Nowadays, the power quality is not only defined by the continuity of electricity but also characterized by parameters such as frequency and magnitude of the supply voltage, current and voltage harmonics, voltage sags, voltage swells, flicker, phase imbalances etc. In today's environment, electronic loads are very sensitive to harmonics, sags, swells and other disturbances. So, power quality has become as important as the continuity of the electricity [1].A number of solutions exist to reduce the undesirable effects of harmonics. The most conventional method is installing passive harmonic filters to remove harmonic currents which present a low cost solution possessing simplicity and efficiency characteristics. But, Passive filters have many drawbacks such as low dynamic performance, source loading, resonance problem, and sensitive to signal variations [2]. As a result, the preceding drawbacks of passive filters have increased the attentions on active power filter solutions. The APF concept is to use an inverter to inject currents or voltages harmonic components to compensate the load harmonic components. The APF can be installed in a low voltage power system to compensate one or more load and can avoids the propagation of current harmonics in the system. As APF compensate the reactive power and cancel the harmonics, it is also termed as active power line conditioners (APLC).

The three main factors of an active power conditioner are:

- The configuration of power converter (the scheme and the topology of converter used)
- The control strategy (the calculation of control reference signals)
- The control method used (how the power inverter follows the control reference strategy)

However for large power applications, it is difficult to implement a low cost PWM converter. Moreover, currents injected by APF may be absorbed by passive filters which may previously be installed into the AC system [3]. As a result, various hybrid filter topologies which combine the conventional harmonic filtering method of passive filters, and active power filters have been developed. Hybrid filters provide effective harmonic compensation specifically for high-power nonlinear load.
A hybrid power filter topologies composed of active and passive components in s aiming to improve the compensation characteristics of both passive and active, thus leading to improvements in cost and performance [4].

However the series active power filter with shunt passive filter configuration is the most appropriate and can reduce both current and voltage harmonics [5].

There are different hybrid filters based on the circuit combination and arrangement. They are classified as shown in fig 1.1 below as

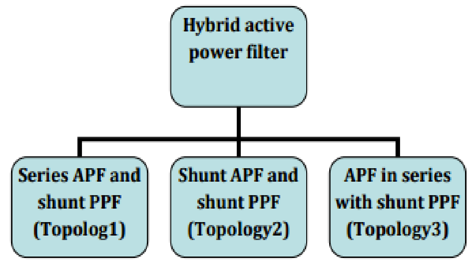

Fig. 1.1: General classification of hybrid active power filter.

2. System Configuration and Basic Compensation Principle

Figure 2.1 shows the power scheme of Hybrid power filter proposed in this paper and designed to reduce the harmonic contents below 5% as per IEEE standards [6]. It consists of a three-phase three wire supply voltage, three phase six pulse rectifier, the active filter which is directly connected to the system through the tuned LC filter.

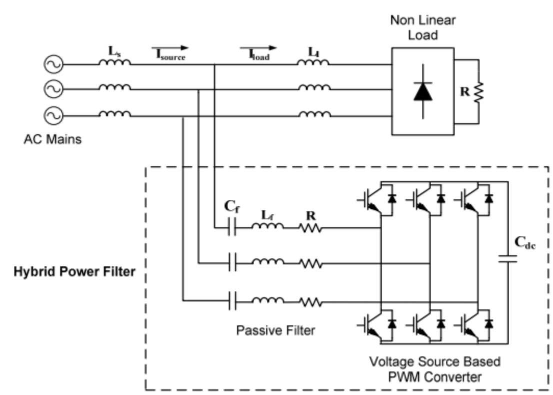

Fig. 2.1: Hybrid Active Power Filter.

The LC filter is tuned to dominant harmonic component of the load to absorb the current harmonics arising from the non-linear load. The power circuit of the inverter consists of an energy storage element of a DC link capacitor and controllable semiconductor switches along their anti-parallel diodes. In traditional voltage source active power filter topology, the DC link capacitor voltage is required to be higher than the peak value of the utility voltage otherwise the generated compensation currents may not be injected in to the mains. However, the presence of filter capacitor in this topology ensures a reduced DC link voltage and a low rated voltage source converter at the cost of additional fundamental current, passing through the converter. As a result, for low voltage applications, PWM converter can be developed by power MOSFETs instead of using IGBTs so that, the initial cost of the converter can be reduced by using MOSFETs. Similar to conventional VSC based APFs; hybrid power filter does not require a DC power supply for its DC link voltage regulation. The required voltage can build up with an appropriate control.

In order to get the compensating principle of the shunt Hybrid Power Filter, the system can be simplified by obtaining its single phase equivalent circuit as indicated in (Fig. 2) where Zs represents the source impedance and Zf represents the passive filter impedance. The non- linear load is shown as an ideal current source, and the APF is considered as a voltage source.

If there is no fundamental component across active power filter terminal voltage than voltage across PWM inverter can be calculated as K×Ish at harmonic frequency where 'h'stands for harmonic component representing feedback gain.

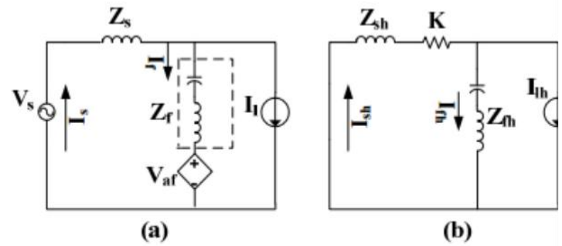

Fig. 2.2: (a) Single Phase Equivalent Circuit (b) Harmonic Equivalent Circuit.

Assuming the source voltage sinusoidal, the following equations can be obtained by applying Kirchhoff's voltage law

$$V_{sh} - I_{sh}Z_{sh} - I_{th}Z_{th} - V_{af} = 0 \quad (1)$$

Where:

$$V_{sh} = 0 \text{ And } V_{af} = KI_{sh}$$

$$I_{sh} = I_{lh} + I_{fh} \quad (2)$$

Combine (1) and (2):

$$I_{sh} = \frac{Z_{fh}}{Z_{fh}+Z_{sh}+K} \quad (3)$$

Eq.(3) indicates that as the active power filter is connected to the system, feedback gain K acts as a damping resistor which ceases the resonance between the supply and the passive filter. Theoretically, as K approaches towards infinity, the harmonic content of the source current goes towards zero. Hence the design procedure of shunt hybrid filter can be divided into two groups as the design of the passive filter and the design of the active filter part. The design of the passive filter includes the calculation of the LF, CF parameters considering the harmonic content of the load connected. The tuning frequency of the passive filter should hose to be the most dominant harmonic component of the non-linear load. Today's industrial loads generally consist of three phase diode rectifiers as AC/DC converters than PWM converters due to their low cost and efficiencies.

Although the 5th harmonic current content f a diode rectifier is higher than its 7th harmonic components, it is more logical to tune the passive filter around 350Hz.An LC filter tuned at 350 Hz shows low impedance at 550 Hz and 650 Hz than a passive filter tuned at 250 Hz frequency. Moreover, for the same value of a filter inductor (Lf), the capacitor required for a 7th harmonic filter is less bulky than as compare of a 5th order harmonic filter. An LC passive filter tuned at 350 Hz amplifies the 5th order harmonic current components at the mains side. [7]

3. Control algorithm

Control circuitry of hybrid power filter can be broadly classified into two categories reference current generation and switching signal generation. Various control techniques in time domain and frequency domain has been used. Frequency domain analysis uses Fourier analysis; wavelet analysis methods while in time domain are instantaneous reactive power theory, synchronous reference frame theory for reference current generation.

The main benefit of time domain method when compared with frequency domain method is the fast response. For the switching signal generation, the methods like sinusoidal pulse width modulation, hysteresis band controller, and space vector modulation techniques are taken into consideration. For low voltage applications some specific methods are prefer [8] which have been discussed in detail in rest of the review.

3.1 Reference Current Generation

The reference current and voltage can be generated using the methods discussed below.

a) Fourier transform based extraction method- Fourier transform is used to separate harmonics from source and load current which is the reference for the hybrid filter to generate compensating current or voltage. The inverse transformation is then applied to generate the compensating reference signals in the time domain. The main characteristic of this method is its suitability for the cases where loads are varying in nature. The main disadvantage is time delay for sampling and computation of Fourier transform [5, 9]. The block diagram of this method is given in the fig.3.1.

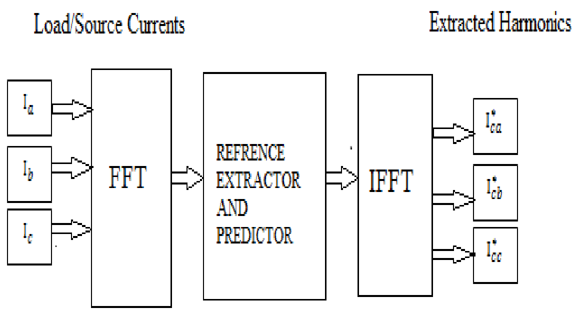

Fig. 3.1: Block diagram of Fourier transform based extraction system.

b) Instantaneous Reactive Power Theory- The p-q theory is derived from instantaneous active and reactive powers in the time domain by using instantaneous voltage and current components on αβ0 coordinates. It uses a transformation; from a stationary reference a-b-c to αβ0 coordinates [7]. This method is applicable to three phase system under balanced load conditions.

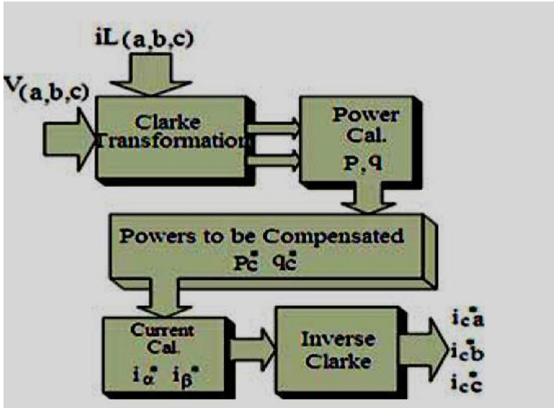

Fig. 3.2: Instantaneous reactive power theory.

c) Synchronous reference frame method- The basic principle of synchronous frame reference is that the current or voltage signals are transformed using Park transformation in to the rotating reference frame [7].The fundamental components are transformed using a low pass filter and inverse park transformation is used to get stationary abc reference frame assuming that voltage waveform is sinusoidal. Synchronous frame reference method with direct control techniques shown in fig.3.3.

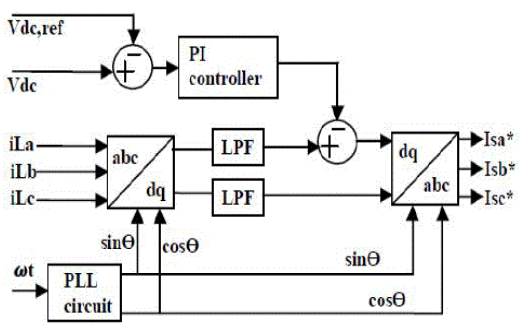

Fig. 3.3: Synchronous reference frame method with direct control scheme.

Comparison table: Table-1 shows the comparison between p-q & SRF method.

Table 1: Comparison between p-q & SRF methods.

Parameters	p-q method	SRF method
Harmonic distortion effects of source voltage	Yes	No
Unbalanced load effect	Yes	No
Calculation complexity	Complicated	Middle
With reactive power compensation	No	Yes

3.2 Switching signal generation

The various methods used for the generation of switching signals as P/PI/PID controllers, Hysteresis PWM, Sinusoidal PWM, Space vector PWM , Soft computing techniques etc.[5]

a) The hysteresis band control technique is shown in fig.6. as an instantaneous feedback current control method in which an actual current continuously tracks the command current as per defined hysteresis band. If the actual current exceeds the hysteresis band, the upper device of Inverter Bridge is turned off and the lower device is turned on or vice versa. If width of hysteresis band is reduced, the harmonic quality of will improve definitely but the switching frequency will rise, which will further cause higher switching losses.

The advantages of Hysteresis Band controller are low cost, dynamic response is excellent and can be implemented easily while disadvantages are high current ripple even in steady state II, Variation of switching frequency and the modulation index generate sub harmonic components[10].

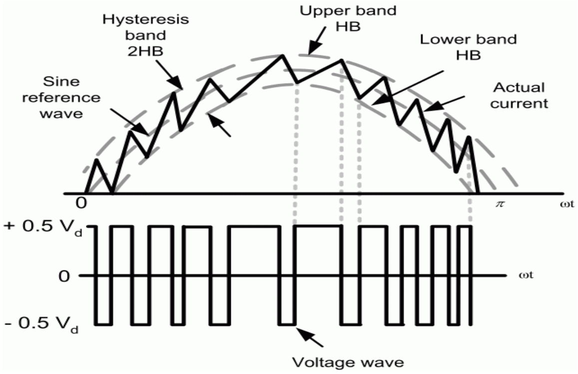

Fig. 3.4: Principle of hysteresis bandwidth controller.

b) Sinusoidal PWM Technique- Sinusoidal pulse width modulation generates a sinusoidal signal by extracting output waveform with varying width. The desired output voltage is obtained by changing the frequency or amplitude of the reference or modulating signal. The change in the amplitude and frequency of the reference voltage varies the pulse width patterns of the output voltage, but keeps sinusoidal pattern. The principle of SPWM is shown in fig.3.5 as given below

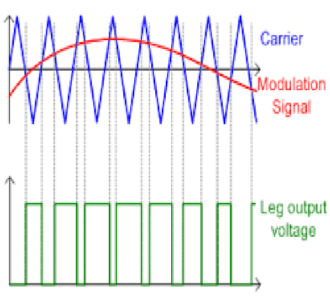

Fig. 3.5: Principle of SPWM.

However Sine PWM is more effective in reducing the Lower order harmonics as compared to hysteresis band PWM with low switching losses and simplicity [7, 9].

4. Conclusion

Power quality is the ability of electrical equipment to operate in a satisfactory manner without adversely affecting the operation of other electrical equipment connected to the system. To overcome the problem of higher rating and cost issues of active filter and resonance problems of passive filter, many types of hybrid filter have been developed. From the comprehensive review of hybrid active power filters, it is observed active power filter in series with shunt passive filter is most preferred topology for power quality improvement. Different harmonic extraction methods, their applications in specified ratings and comparisons have been analyzed in the later parts.

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