HARMONIC SIGNATURE AND ITS MITIGATION USING ACTIVE FILTERS

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***ABSTRACT*:** *This paper describes shunt active power filters which is used for elimination of harmonic form the current waveform in power system. basics of harmonic and reason of its presence i.e. non- linear loads are described. Here signature of harmonic in various equipment's and its effect on power system is illustrated. Mitigation of these harmonics by use of various configurations of filters along with various control strategies is presented. Pro.s and cons. of active filter along with the limitations of the passive filter are explained.*

Keywords— Harmonic, Passive filters, Active filters, Shunt active filter, Harmonic distortion

I: INTRODUCTION

To Significant development and usage of power electronic converters, introduces non-linearity and hence high degree deterioration of current wave shape due to presence of harmonic [7] and leads to deterioration of power quality of the power system. Presence of harmonics due to such non linearity introduces following problems:

- Greater power losses in distribution system.
- Electromagnetic interference in communication system
- Operation failure of protective devices.

These problems leads to high capital costs so as to mitigate the adverse effect of harmonics or otherwise there will be a substantial decrease in productivity and poor quality in the products or services [3].

A harmonic is component of periodic wave having a frequency that is an integral multiple of the fundamental power line frequency [4]. Harmonics are by product of modern power electronics devices and equipment. It is measured in terms of Total Harmonics Distortion (THD). Here THD is nothing but the contribution of all harmonic frequency current to the fundamental. Distortion in the wave shape is largely due to abrupt rise in the usage of non-linear loads e.g. personal computers; uninterruptible power supplies (UPSs), variable frequency devices (AC and DC) or any electronic devices. Effect of harmonics on the distribution system can further be segregated in two parts: (a) shorts- term and (b) long term effect. Long term effects are usually related to increased resistive losses or voltage stresses [7] [2].

Harmonic distortion from the current wave shape can be mitigated by using power filters which can further be classified as passive and active power filters, based on the components used therein. The passive filter is simple to build and also is a cost effective solution to reduced harmonic distortion. Its usage is restricted in modern times due to the advent of power electronics switches and hence of the development of active power filter. The reason is self-evident from the facts highlighted in the following topic.

Active filter proves to be advantageous over its counterpart passive filter as it eliminates possibilities of above mentioned problems associated with passive filters [2].

II: BASIC OF HARMONIC

Harmonic in voltage or current waveform can be considered as perfectly sinusoidal components of frequencies multiple of the fundamental frequency.

$$f_h = (h)*(\text{Fundamental frequency})$$

Where h is integer.

For example, if waveform has fundamental frequency f, the second harmonic will have frequency $2*f$ and the third harmonic will have frequency of $3*f$, i.e. for the fundamental frequency of 50 Hz, the second and third harmonics would have frequencies 100 and 150 Hz respectively [4].

Various properties of harmonics are described as:

- Their frequency is multiple of fundamental frequency.
- The amplitude of sine wave decreases with increase in harmonic frequency.
- Odd symmetry is characterized by $f(-t) = -f(t)$ and results in no cosine terms in the waveform Fourier series expansion. If the current waveform

approaches the appearance of a square wave, it is rich in odd order harmonics.

- Even symmetry is characterized by f (-t) = - f (t) and results in the waveform Fourier series expansion having no sine terms, that is only cosine terms. Every order harmonics produces triangular wave.
- The individual frequency harmonic components are of entirely positive, negative or zero sequence in a balanced three phase system.
- If harmonics are present, then zero and negative sequence current exists even if system is balanced.
- Triplen harmonics cannot flow in delta or in absence of ground connection being zero sequence.
- The two halves of the complex wave are identical in shape, in other words there is no distortion, and this is always the case when only odd harmonics are present.
- The two halves of complex wave are not identical when even harmonics are present [7].

A. Linear and Non-Linear Loads

a. Linear Loads

In linear loads, voltage and current signals are very close to each other. For example Ohm's law, where voltage drops across resistance is direct function of current passing through it. If pure sinusoidal voltage is applied to the resistive element, the shape of the current and voltage waveform would be purely sinusoidal i.e. without any distortion.

b. Non- Linear Loads

In non-linear loads, the voltage and current waveforms are not proportional to each other. Such type of loads are responsible for generating harmonics in the current waveform which in turn, leads to distortion of voltage waveform; under such condition the voltage is no longer proportional to the current [6] [5].

Sr. No.	Linear Loads	Nonlinear Loads
1	Example; Power Factor Improvement capacitor, Heaters Etc.	Example; Computer, Laser Printer, SMPSs, Rectifier Etc.
2	Ohm's law is valid	Ohms law is not valid
3	Load current does not contain harmonic.	Load current contains odd harmonics.
4	Could be inductive or capacitive.	Can't be categorized as leading or lagging loads
5	May not demand high inrush current while starting.	Very high current drawn while starting

Table 1: Comparison between Linear and Non-Linear Loads

B. Individual and Total Harmonic Distortion

Individual harmonic distortion (IHD) is the ratio between the root mean square (RMS) value of the individual as well as RMS value of the fundamental harmonics.

$$IHD_n = \frac{I_n}{I_1}$$

Total harmonic distortion (THD) is ratio between the RMS value of the harmonics and the RMS value of the fundamental [4] [7].

$$THD = \frac{I_H}{I_1} \times 100\%$$

C. Harmonic signature and harmonic effect

a. Harmonic Signature

Most of the installed loads in present day power system are harmonic current generators. It produces harmonic when combined with the impedance of the electrical system. Although, Fluorescent lamps seems to use less electrical energy for the same output as that compared to Incandescent lamps, it produces substantial harmonic current in the process due to presence of solid state or so called electronic ballast. The non-linear characteristic of personal computer is responsible for introduction of harmonics. Arc devices (Electrical furnace, Soldering equipment) are also the sources of harmonics. Also, the large inrush current during switching of capacitor banks, transformer, and rotating machine into the distribution system can develop harmonic current [4].

b. Effects of Harmonics

The effect of harmonics on loads or power sources depends on their sensitivity to voltage or current distortion. The heating equipment's are least affected by distorted voltage or current waveforms whereas the electronic devices designed to operate on pure sinusoidal fundamental frequency voltage or current waveforms are heavily affected. In transformer, the voltage harmonics causes additional losses in the transformer's core whereas the higher frequency harmonics set up hysteresis loops [4]. Electrical motors lies in between these two categories as far as harmonic effect is concerned [6].

III: PASSIVE FILTERS

Passive filters, as the name suggests, are generally constructed using combinations of passive elements such resistors, inductors and capacitors. The type of harmonic source decides the structure of filter to be implemented [2]. The figure 1.1 shown below depicts the common type of passive filter with their different configurations. The most common and economical type of passive filter is the single tuned “notch” filter. The notch filter is connected in shunt with power distribution system and is series tuned to present low impedance to a particular harmonic current. Another popular type of passive filter is the high-pass filter (HPF). It typically takes on one of three forms shown below. The first order is rarely used as it causes large power losses at fundamental frequency. The second order HPF is simplest to apply and it also provides good filtering action with reduced fundamental frequency losses. In filtering performance, the third order HPF is superior to that of second order HPF. However, it is not commonly used for low or medium voltage application since economic, complexity, and reliability factor do not justify them [7].

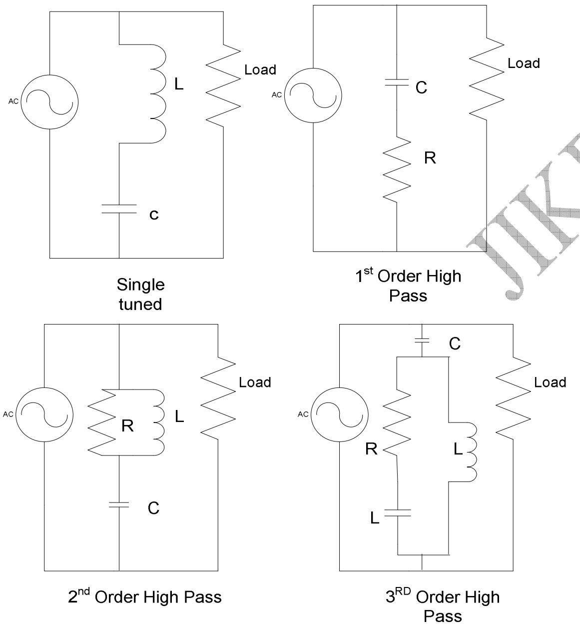

Fig. 1 Common types of filter and configuration [7]

The passive filter is very bulky because the harmonic to be suppressed by it are of lower order harmonics. The filter design is heavily dependent on the power system in which it is to be connected. The passive filters are known to cause resonance and hence affect the stability of the power distribution system. The size of the filter component becomes impractical if the frequency variation is large. The series and parallel resonance and a fixed characteristic are the main drawbacks of passive LC filters [7].

a. Disadvantages of the passive filter

They only filter the frequencies they were previously tuned for.

Their operation cannot be limited to a certain load.

At a specific frequency $f_0 = 1/(2\pi\sqrt{(L_s + L_F)C_F})$ there is always anti resonance between the source impedance and the passive filter (condition of parallel resonance), which is also called load harmonics amplifying phenomena.

The passive filter may fall into series resonance with the power system, so that voltage distortion produces excessive harmonic currents flowing into the passive filter.

Ageing of the passive components causes change in the pass band frequency and hence some error in the operation is introduced with the passage of the time.

b. Advantages of the passive filter

It provides reactive compensation needed by the harmonic producing devices.

Its cost is low as well as design complexity is considerably reduced which further lower its cost of operation as well as its maintenance.

IV: ACTIVE FILTERS

Active power filters can compensate for harmonic without fundamental frequency reactive power concerns. Therefore rating of the active power filter can be less than a comparable passive filter for the same non-linear load and the active power filter will not introduces system resonance that can move from one frequency to another [2].

A. Classification

- There are basically of following types
  - The shunt type
  - The series type
  - Hybrid filters i.e. active filters combined with passive filters
  - Unified power flow controller (UPFC) i.e. active filters of both types (series and shunt) acting together

- Classification of Active Filter

An active power filter can categorically be classified in the different ways as follows

- Converter based classification
  - VSI (voltage source inverter)
  - CSI (current source inverter)

- Topology based classification
  - Series active power filter
  - Shunt active power filter

- Supply system based classification
  - 1-Ph, 2 wire

- 3-PH, 3 wire
- 3-PH, 4 wire

- Control based classification
  - PWM (pulse width modulation)
  - Hysteresis band current control
  - Sliding mode control
  - Dead beat control
  - Neuro / Fuzzy-logic based control

- Compensation based classification
  - In frequency domain
  - Fourier analysis method

- In time domain
  - Instantaneous reactive power (p-q) theory

- Topology based classification

a. Shunt Active Power Filter

A shunt active power filter consists of a controllable voltage or current source. The voltage source inverter based shunt APF acts as a current source, compensating the compensating current due to non-linear loads. The operation of shunt APF is based on injection of compensated current equal to distorted current, thus eliminating original distorted Current [6].

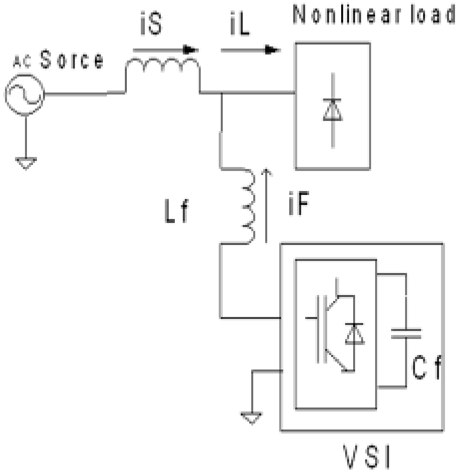

Fig. 2 shunt active power filter [1]

b. Series Active Power Filter

The basics of series active filter are shown in fig. 3 below. The transformer is used to connect it to the power system. The compensating voltage is used to cancel the voltage harmonic of load [6]. The operation principle of the series APF is based on the isolation of the harmonic in between the nonlinear loads and the source. However, the main advantage of series APF over shunt is that they are ideal for voltage harmonic elimination. It provides the load with a pure sinusoidal waveform, which is important for voltage sensitive devices such as power system protection devices [7].

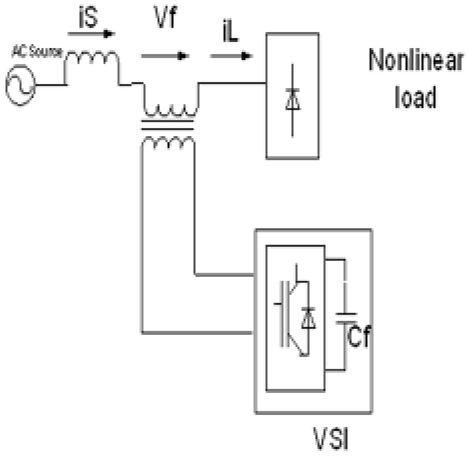

Fig. 3 series active power filter [7]

	Shunt Active Filter	Series Active Filter
Power circuit of Active Filter	Voltage–fed PWM inverter with minor loop current source.	Voltage –fed PWM inverter without minor loop voltage source.
Active Filter acts as	Current source	Voltage source
Additional Function	Reactive power compensation	AC voltage reduction

Table 2: Comparison of Shunt and Series Active Filter [3]

c. Hybrid Active Power Filter

The combination of static and passive filters called hybrid active power filter is used in order to reduce the cost of the static compensation. The role of passive filter is to cancel the most relevant harmonics of the load, and the active filter is dedicated to improving the performance of passive filters or to cancel other harmonic components. It, therefore, results into reduction of the total cost decrease without reduction of efficiency [7].

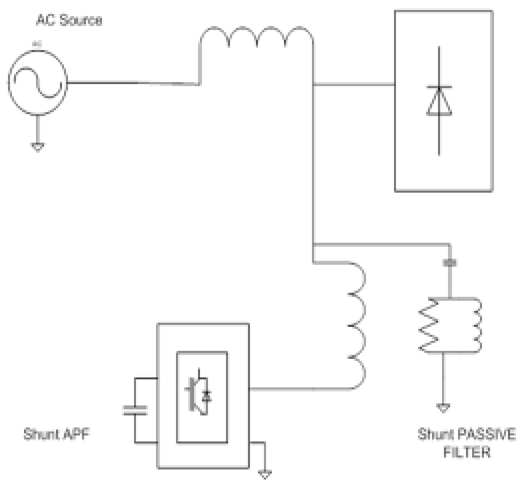

Fig. 4 Hybrid filters with a shunt passive filter and shunt active filter [7]

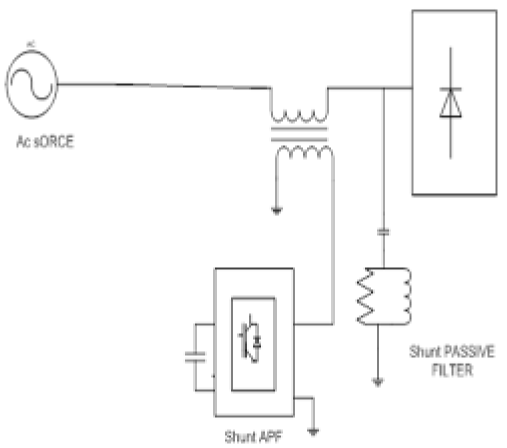

Fig. 5 Series APF and shunt passive filter [7] Supply system based classification

- Supply system based classification

a. Two wire (single phase) system

Two- wire (Single phase) system is available based on converter configuration or mode of configuration. Based on mode of configuration, they are available as active series, active shunt and combination of both. Whereas based on converter configuration, they are available as current source PWM with inductive energy storage elements and voltage source PWM with capacitive dc-bus energy storage elements.

b. Three or four wire three phase system

Several nonlinear loads with three phase configuration are available. It is possible to use three single phase inverters as an APLC power circuit for the unbalanced loads involving three phases four wire systems. The main goal of using such configuration is to compensate phase by phase. Therefore, it is usual to use APLC with three phases in four wire power systems. The split capacitor is essential on DC side in this case.

VI: Conclusion

The extensive use of power electronic devices is the major source of harmonics in present era. The presence of harmonics they are responsible for causing additional core losses in describes various filters used to eliminate harmonics with their configurations. The harmonic filters mainly fall into categories of passive, active and hybrid filters. The use of passive filters reduces harmonics but they have large size and produces resonance causing stability problems. The active power filter is superior to passive filter in not causing resonance problem. Hybrid filter have advantage over both passive and active filters because this filter improves the system performance of high order harmonic while provides a cost-effective low order harmonic mitigation.

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