Enhancement of Power Quality in Domestic Loads using Active Power Filters

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Abstract

This paper will present modern times current harmonics related problems in domestic loads. Current harmonics are produced due to use of non-linear loads in domestic applications. In this paper a non-linear load is modelled in place of similar domestic load to serve as the test load. Also different methods are studied for mitigation of current harmonics for domestic applications. The active power filter's steady state response was evaluated using PQ theory in MATLAB.

Keywords: Power quality problems, Non-linear loads, Harmonics, PQ theory.

1. INTRODUCTION

Previously, when the era of commercial power generation, transmission and distribution began, the major of the load was linear load for examples motors, incandescent lamp, etc. The widespread use of equipment, such as, Programmable Logic Controllers (PLC), Adjustable Speed Drives (ADS), Semi-conducting devices etc. has led to increase in number of power quality problems. Due to their non-linear nature, all these loads cause disturbances in form of current and voltage harmonics [1]. A number of customer's equipment also disturb the power system as they are non-linear in nature.

Power quality also gets disturbed due to use of step-down transformer in case of house hold appliances to reduce voltage to a particular level. The inventions of diodes and transistors and their wide acceptance in all types of applications made the load non-linear in nature. Also the use of Switched Mode Power Supply (SMPS) has led to increase in certain undesirable contents being injected back to the power system. One of them is Harmonics, which are components present in waveform that are the multiple integral of the fundamental frequency. Harmonics have various hazardous effects on power system such as it affects operation of sensitive equipment, increased losses, reduction in overall life of equipment, etc.

Some of the commonly used domestic loads which are non-linear in nature are chargers, computers, TVs, LEDs, etc. as these equipment draw harmonics current it will affect the functioning and life of different power system components between source and load.

2. POWER QUALITY

Many definitions are present in the literature for the word Power Quality. In general, power quality refers to quality of voltage and current. On utility side, it means delivery of reliable power and for customer, it means uninterrupted power supply. The aim for both, user and utility is to achieve their end-goal that is quality of power is maintained. Majority of power quality problems are caused at utilization end which then propagates through the power system.

Power quality problems can be classified into voltage fluctuations, harmonics, waveform distortion, transients, voltage imbalance, etc. These problems may be caused due to switching On/Off heavy loads, load switching, non-linear loads, etc. The effects of power quality problems are heating of motor, increased losses, Electromagnetic interference, and failure of equipment. Harmonics is one of the power quality problem which is more prevalent than other because of its effects on power system. Main reason for causing harmonics in current and voltage waveforms is the non-linear nature of loads. Harmonics are components present in the waveform that are in multiples of the fundamental frequency. This can be observed both in voltage and current, with current harmonics being more pronounced. The non-linear nature of the loads and the switching involved causes the current to be drawn in pulses which can sometimes have sharp rising or falling edges. Current harmonics can lead to voltage harmonics [7].

3. ACTIVE POWER FILTERS

Active power filters (APF) are power filters, which can perform the job of harmonics mitigation. Active power filters can be used to mitigate harmonics in the power system which are significantly below the switching frequency of the filter. The active power filters are used to filter out both higher and lower order harmonics in the power system.[1]

The main difference between active power filters and passive power filters is that APFs mitigate harmonics by injecting active power with the same frequency but with reverse phase to cancel that harmonic, where passive power filters use combinations of resistors (R), inductors (L) and capacitors (C) and does not require an external power source or active components such as transistors. This difference, make it possible for APFs to mitigate a wide range of harmonics.[2] APFs are classified into shunt, series and hybrid filters. Shunt APFs are mainly used for current harmonics mitigation, series APFs are used for voltage harmonics problems. Hybrid APFs are the combination of active and passive filters. Usually the inverter stage of active power filters is made from Voltage Source Inverters or Current Source Inverters.

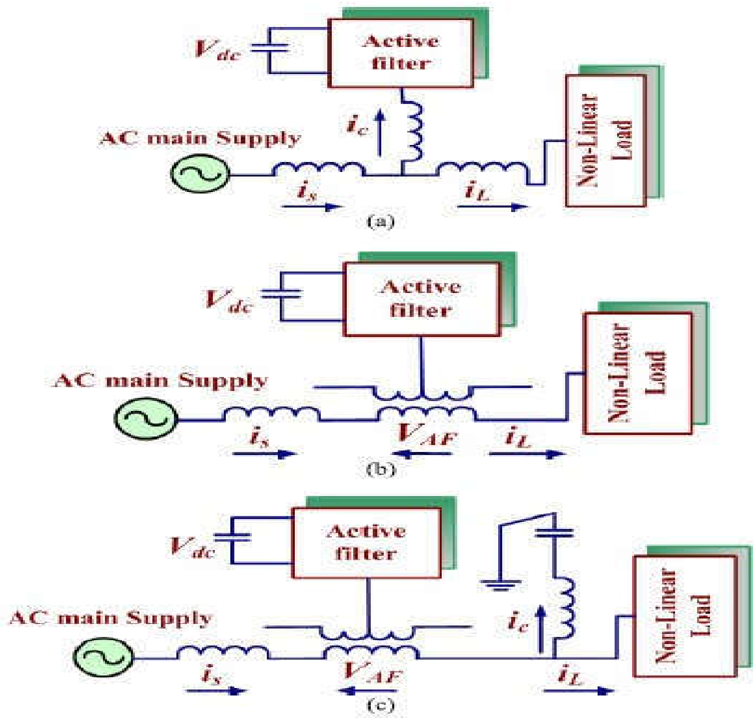


Figure 1. Different topologies of Active power Filter [1]

4. HARMONICS ANALYSIS OF DOMESTIC LOADS

The main purpose of this paper is to mitigate current harmonics in domestic loads. So it is necessary to understand harmonic analysis of domestic loads.

1) Incandescent lamp

The main element of incandescent lamp is tungsten filament enclosed along with inert gas. By nature this filament is resistive and so the current and voltage waveforms are almost sinusoidal and are in phase with each other.

2) Switched mode power supply (SMPS)

Many of the commonly used devices TV, charger, PCs make use of SMPS for their requirement of power. The advantage of using SMPS is their high power density and high power output. SMPS consists of rectifier stage with capacitor which causes current pulse which are often short and have a sharp edge. Due to this, distortion can be seen in the current waveform of SMPS and so caused high % THD.

3) LED lamps

The use of LED lamps has increased over the years with the world shifting towards energy efficient lighting. Usually LED lights make use of SMPS so that to provide constant current supply. SMPS consists of rectifier stage with capacitor which causes current pulse which are often short and have a sharp edge. Due to this, distortion can be seen in the current waveform of SMPS and so caused high % THD.

5. SHUNT ACTIVE POWER FILTER

Figure 1 shows the basic block diagram of working of shunt active power filter. SAF provides compensation for harmonics current produced by the use of nonlinear load in power system. It does this by injecting equal but opposite compensating current into the power system. SAF acts a active current source that generates current in equal magnitude but phase shifted by 180 to that of harmonics current and injects this into the system which provides the compensation. Figure shows all the components of SAF, the load current that contains harmonics, the source current and the compensating current generated by the SAF for that adds to the load current, to make the supply sinusoidal. It can be proved that before compensation the source current are non-sinusoidal due to presence of harmonics but after the compensation provided by SAF the source current becomes sinusoidal if appropriate technique is implemented.

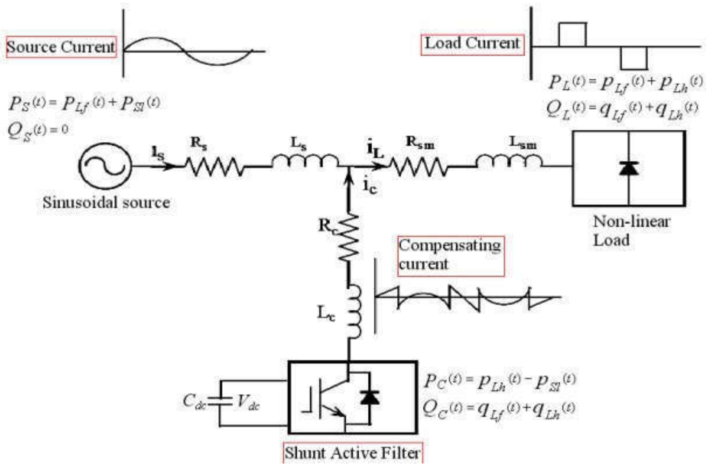


Figure 2. Shunt Active Power Filter [1]

6. MATHEMATICAL MODEL FOR REFERENCE CURRENT EXTRACTION

The Instantaneous power theory or p-q theory was proposed by Akagi in 1983. This theory is applicable for steady state as well as transient state. Also it can be applied for three phase system with or without neutral wire. Firstly the three phase voltages and current are transformed to α-β-0 coordinates with the help of Clark's transformation then the instantaneous values of active and reactive power are calculated.

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad (2)$$

From equations the instantaneous real power and instantaneous imaginary power on αβ axes can be expressed as

$$\begin{bmatrix} p = \bar{p} + \tilde{p} \\ q = \bar{q} + \tilde{q} \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ -V\beta & V\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \quad (3)$$

Above equations contains the average power as well as oscillating components of real and reactive power. The oscillating components represent the present of harmonics in load current. Using shunt active filter the harmonics component in load current can be compensated and the source current thus can be made sinusoidal.

The equations for compensating current reference in αβ axes can be written as

$$\begin{bmatrix} i_{\alpha}' \\ i \end{bmatrix} = \frac{1}{V\alpha^2 + V\beta^2} \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (4)$$

Finally by Inverse Clarke transformation the compensating current reference are expressed as

$$\begin{bmatrix} i_{ca}* \\ i_{cb}* \\ i_{cc}* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{\alpha} \\ i_{\beta} \end{bmatrix} \quad (5)$$

7. MODELLING OF NON-LINEAR LOAD

Shunt active filters are used to deal with the problems related to current harmonics due to the use of nonlinear loads in the system. Shunt active filter provide compensation for current harmonics and also help to maintain DC link voltage. Among many available methods to generate reference current for active filter, in this thesis instantaneous power theory (p-q theory) is used to generate reference current and then this signals are given to hysteresis current controller for generating switching signals.

Simulation of shunt active filter is done using MATLAB simulation tool. When nonlinear load is connected load current and hence the source current gets distorted due to presence of harmonics. Reference currents for active filter are generated using p-q theory and then hysteresis current control is used to generate switching signals.

Hysteresis current control techniques offer very good dynamic response and simplicity in generating the gating signals for active converter. In this method a feedback current control technique is used so that actual current continuously follows the command current limited by a hysteresis band. The control circuit generates the sine reference current wave of desired magnitude and frequency, and it is compared with actual phase current wave. As the current exceeds a prescribe hysteresis band, the upper switch in half bridge is turned off and lower switch is turned on.

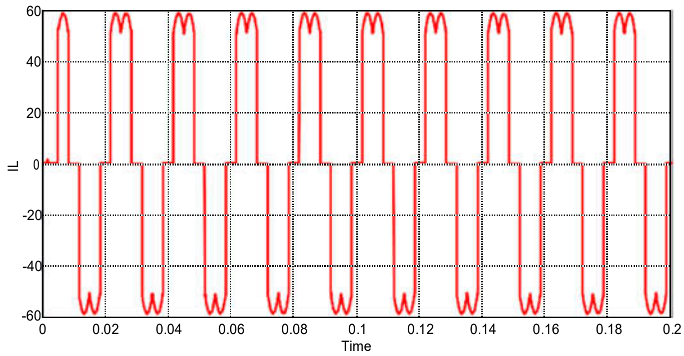
Table 1 Various Parameters Applied to Shunt Active Filter

SYSTEM PARAMETERS	VALUES
AC voltage supply(phase-phase rms)	230 V
Line frequency	50Hz
Non linear Load (3 phase full wave controlled rectifier)	R = 10 Ω L = 1mH
DC side capacitor voltage	325 V
Filter Inductance	0.1mH
DC side capacitor	3500μF
Kp, Ki	0.2, 10

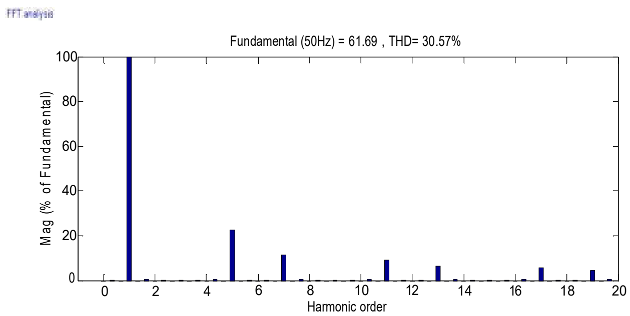
8. SIMULATION RESULTS

Table 2 Results obtained from simulation

Condition in Simulation	THD in source current before active filtering	THD in source current after active filtering
Steady state condition	30.57%	3.94%

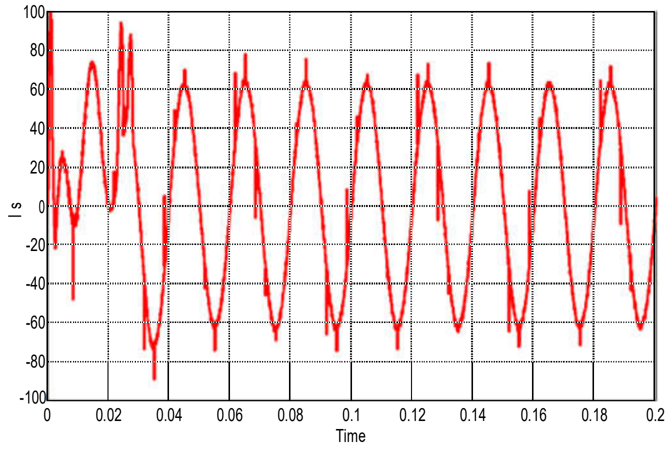


(a)



(b)

Figure 3 Simulation results before compensation (a) Load current (b) THD of Load current



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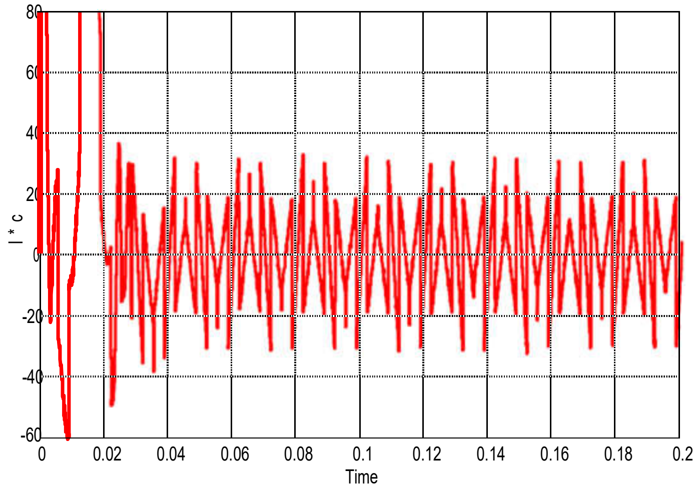

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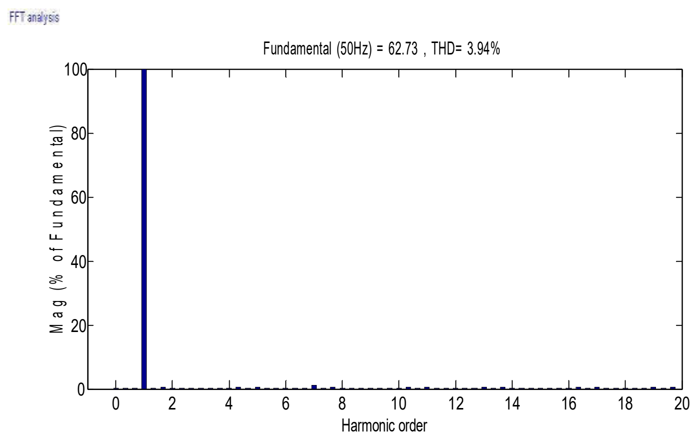

(c)

Figure 4 Results after compensation (a) Source current (b) Compensating current (c) THD of source current

9. CONCLUSIONS

A shunt active power filter has been investigated for power quality improvement. From simulation results it can be conclude that SAF can be effectively used for harmonics current compensation due to nonlinear loads. Also p-q theory can be implemented for steady state as well as transient conditions when the supply voltage is balanced.

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