# Harmonic Analysis and Its Mitigation Using Different Passive Filters

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**ABSTRACT—** ***Harmonics are the by-products of modern electronic devices. Harmonics play a significant role in deteriorating power quality, called harmonic distortion. To mitigate the harmonics, one can install passive or active filters. Though active filters are very effective to compensate harmonic currents and voltages they are still very expensive. Hence, active filters are only installed in large industrial plants while for small installations passive filters are more preferred.***

***In this paper a case study of design and development of harmonic filter for a typical non- linear load is presented. Different filter topologies are designed based on the introduced methods to suppress a benchmark of harmonics. Harmonic survey indicated a current THD of 128%. Then the whole system is simulated with SIMULINK to verify the discussed procedures.***

**Keywords—** Capacitors, Harmonics, Passive filter, Power quality

## 1. INTRODUCTION

The proliferation of electronic switching devices into modern equipment's has resulted in a significant increase in the amount of harmonic pollution in distribution systems. These harmonics if disregarded or undetected may cause harmonic resonant conditions which could present system operating problems resulting in complaints from customers and reduced life of power equipment as well as degraded efficiency and performance. Harmonic currents and voltages can cause many unfavorable effects on the power system itself and the connected loads. Malfunctioning of electronic equipment, capacitor failure, transformer and neutral conductor overheating, excessive heating in rotating machinery are some of these effects.

Passive filters are widely employed to suppress load harmonics. Topology selection of the filters is based on the frequency bandwidth to be suppressed. Among different topologies, single-tuned (ST) and high-pass filters are more popular in power system applications. There are also some filters to eliminate voltage distortions. However, most of filters are applied to cancel current distortion. For system below 66KV, the THD should be less than 5 %.

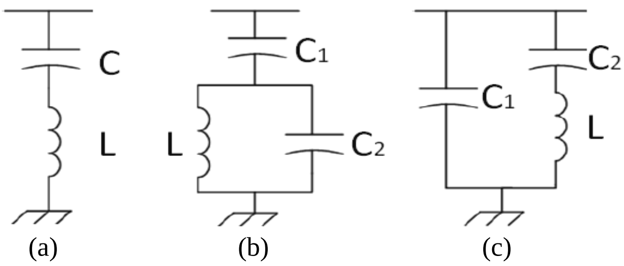


**Figure 1**: Different Filter Topologies (a) ST Filter (b) C Type Filter (c) CCL Filter [5]

## 2. CASE STUDY

Harmonic effects of the power system can be studied for a typical site or load. It involves selecting the site which is mostly affected by harmonics and conducting the harmonic experiment**.**

### *2.1 Selection of Site*

The site should be such that where the presence of harmonic is more. Such kind of site or location are generally where, DC Drives, non-linear loads such as computers, UPS, electronic ballast, induction heating furnace, solid state rectifiers battery charger, etc are more which generate harmonic current in the system. Now a day's computers have become an essential tool for many activities. An engineering college laboratory is no exception to it. Average computer laboratory consists of 15- to 20 desktops, 2 to 3 printers, scanner, networking switches, speakers etc. To get the continuous and stabilized supply UPS systems are used. Computers, printers, scanners are non-linear devices also. CPU is a major source of harmonics. Hence it was decided to conduct harmonic analysis of the computer laboratory.

### 2.2 *Harmonic Survey*

The CPU load of 210 W is selected for harmonic experimental study and is tested for its non-linearity. The conditions of the test are as given below.

Line to Neutral voltage: 228.8 Volts

Current to each phase: 1.5 Amp

Frequency : 50 Hz

Power factor : 0.61 lag

KVA : 0.338

KW : 0.21

Max current : 4.2 A
Voltage Harmonics – THD : 4.8 %
Current Harmonics – THD : 128 %

The following THD is obtained for different order harmonics.

Table 1: Current Harmonics for Phase and Neutral

| *Order of Harmonics* | *THD A (%) $L_1$* | *THD A (%) $L_N$* |
|---|---|---|
| 1 | 100 | 100 |
| 2 | 5.587 | 5.084 |
| 3 | 61.302 | 55.846 |
| 4 | 0 | 0 |
| 5 | 41.854 | 38.078 |
| 6 | 0 | 0 |
| 7 | 22.632 | 20.857 |
| 8 | 0 | 0 |
| 9 | 9.258 | 8.542 |

From the above measurements it can be seen that third harmonic is dominant, also power factor is poor at full load. Harmonic distorted current is prevented from flowing back into the power system by diverting them through the low impedance shunt path called "HARMONIC FILTER". It is essentially a power factor correcting capacitor combined with a series reactor. At frequency higher than tuned point, it behaves as an inductive load. Harmonic filter is not a capacitive load at frequency higher than a tuning frequency. Hence the power system can no longer resonate at any magnitude of either current of voltage distortion. From the readings it seems very clearly that the presence of % harmonic level content is more in order of 3rd harmonic. Hence we will go for **"Detuned Passive Filter"** which eliminates the particular order harmonic and will reduce the overall average effect of nth order of harmonic.

## 3. DESIGN OF HARMONIC FILTER

The filter design consist of inductor design, capacitor design, other protective equipment and indication devices which indicates the on or off of the filter. The reactor should be of 16% of the system voltage for 3$^{rd}$ harmonic where as for the 5th and higher order harmonic it is of 8% of the system voltage.

### *3.1 Single Tuned Filter*

A single tuned filter is a capacitor designed to trap a certain harmonic by adding a reactor with $X_L = X_C$ at the tuned frequency $f_n$. The steps involved in designing ST filter are as follows:

i. Determine capacitor size $Q_c$ in $MVA_r$

ii. Determine capacitor reactance $X_c$

$$X_c = \frac{kV^2}{Q_c}$$

iii. Determine inductive reactance $X_L$

$$X_L = \frac{X_c}{{h_n}^2}$$

iv. Determine inductance and capacitance

$$X_c = \frac{1}{2\pi f_1 C}$$

$$X_L = 2\pi f_1 L$$

v. L and C can be related as

$$L = \frac{1/C}{4\pi^2 f_1^2 h_n^2}$$

Table 2: Designed Values of Single Tuned Filter

| *Filter Elements* | *Order of Harmonics* | | | | |
|---|---|---|---|---|---|
| | 2 | 3 | 5 | 7 | 9 |
| L (mH) | 258.47 | 114.87 | 41.35 | 21.099 | 12.76 |
| C (µF) | 9.8 | 9.8 | 9.8 | 9.8 | 9.8 |

### *3.2 C Type Filter*

As shown in fig.1, C type high pass filter is having two capacitors and an inductor. Determination of the inductance *L* and the capacitances *C*1 and *C*2 is discussed in this section. The steps involved in designing C type high pass filter are as follows:

i. Choose the value of k (k <<< 1). The value of k is chosen here as 0.2

ii. Determine the capacitance $C_1$

$$C_1 = \frac{k\ max(i_L)}{2\pi f_1 V}$$

iii. Determine the capacitance $C_2$

$$k = \frac{C_1}{C_2}$$

iv. Determine the inductance L

$$L = \frac{1/(1+k)}{4\pi^2 f_{max}^2 C_2}$$

**Table 3**: Designed Values of C Type High Pass Filter

| *Filter Elements* | *Order of Harmonics* | | | | |
|---|---|---|---|---|---|
| | 2 | 3 | 5 | 7 | 9 |
| L (mH) | 36.32 | 16.14 | 5.8104 | 2.9645 | 1.7933 |
| $C_1$ (µF) | 11.6252 | 11.6252 | 11.6252 | 11.6252 | 11.6252 |
| $C_2$ (µF) | 58.1262 | 58.1262 | 58.1262 | 58.1262 | 58.1262 |

### *3.3 CCL Filter*

The design of CCL high pass filter is similar to that of C type filter. The only difference is in the position of capacitors. The following are the steps involved in the design procedure.

i. Choose the value of k (k <<< 1) k=0.2 is chosen here

ii. Determine $C_1$

$$C_1 = \frac{k\ max(i_L)}{2\pi f_1 V}$$

iii. Determine $C_2$

$$k = \frac{C_1}{C_2}$$

iv. Determine the inductance L

$$L = \frac{1/(1+k)}{4\pi^2 f_{max}^2 C_2}$$

Table 4: Designed Values of CCL Filter

| *Filter Elements* | *Order of Harmonics* | | | | |
|---|---|---|---|---|---|
| | 2 | 3 | 5 | 7 | 9 |
| L (mH) | 36.32 | 16.14 | 5.8104 | 2.9645 | 1.7933 |
| $C_1$ (µF) | 11.6252 | 11.6252 | 11.6252 | 11.6252 | 11.6252 |
| $C_2$ (µF) | 58.1262 | 58.1262 | 58.1262 | 58.1262 | 58.1262 |

## 4. SIMULATION RESULT AND ANALYSIS

The CPU load of 250W is tested for the non-linearity and individual harmonics are simulated in MATLAB SIMULINK software. The source current is having a THD of 80.54%.

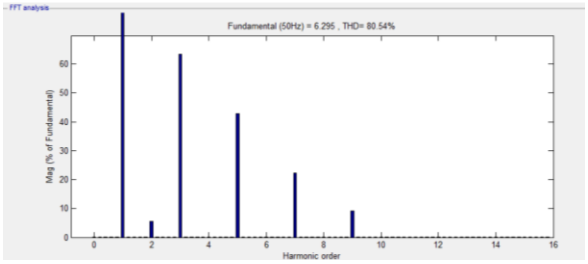


**Figure 2**: FFT Analysis without filter

### *4.1 Single Tuned Filter*

Single tuned filters are designed to cancel out $2^{nd}$, $3^{rd}$, $4^{th}$, $5^{th}$, $7^{th}$ and $9^{th}$ harmonics. FFT analysis of the source current using ST filter is shown below. THD ampere has reduced from 80.54 % to 0.42 %. THD voltage has reduced from 2.83 % to 0.13 %. The power factor is found to be 0.86 lagging.

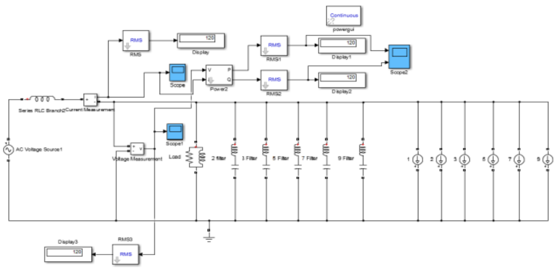

**Figure 3**: Simulink model of single tuned filter

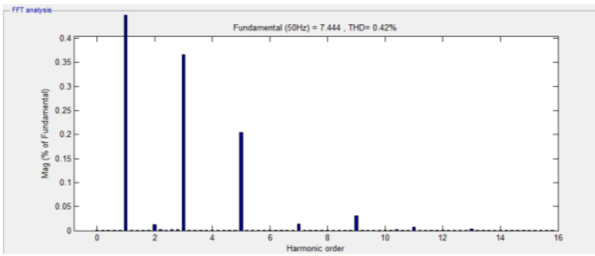


**Figure 4**: FFT Analysis of source current with single tuned filter

### *4.2 C Type Filter*

The power system with non-linear load is simulated using C type high pass filter. It is observed that the current harmonics has reduced from 80.54 % to 0.81 %, whereas the voltage harmonics has reduced from 2.83 % to 0.06 % and the power factor is 0.84 lagging.

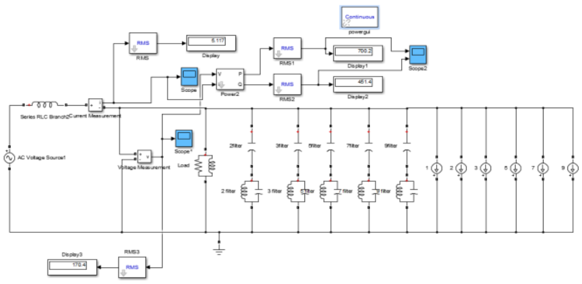

**Figure 5**: Simulink model of C type filter

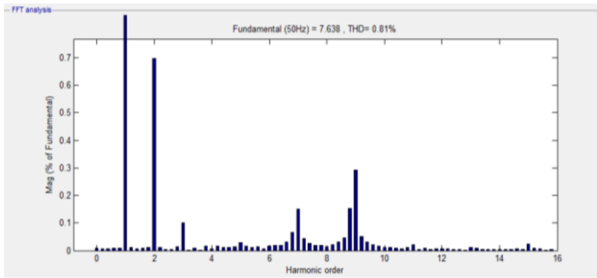


**Figure 6**: FFT Analysis of source current with C type filter

### *4.3 CCL Filter*

CCL filter is simulated in Matlab Simulink software and it is found that the THD A has reduced from 80.54 % to 41.24 % whereas the THD V got amplified to 6.74 % from 2.83 % particularly the fifth harmonics. As a remedial solution to this problem, a CCL filter can be combined with a single tuned filter tuned to fifth harmonics can be used. The power factor is found to be 0.27 lagging.

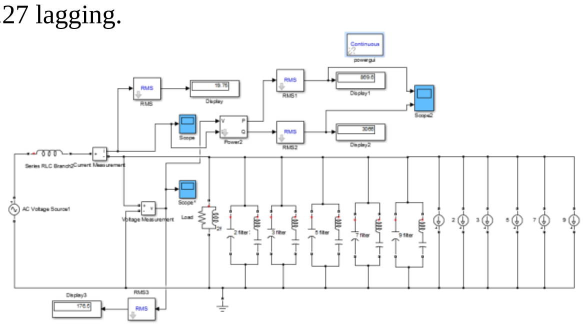

**Figure 7**: Simulink model of CCL filter

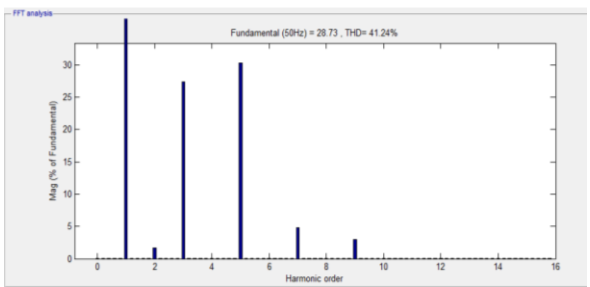


**Figure 8**: FFT Analysis of source current with CCL filter

## 5 CONCLUSION AND FUTURE ENHANCEMENT

This paper has presented the results of the harmonic analysis of a typical non-linear load. Here various harmonic filters are designed for the non- linear load in computer laboratory of an educational institution. Efficient and comprehensive design procedures of single-tuned and C-type passive harmonic filters are appropriate for low power applications. CCL filter can be combined with single tuned filter to improve power factor and to reduce the THD.

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