Comparative Analysis of Passive Filters To Mitigate Harmonics

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***Abstract*— This paper presents a comparison of single tuned, double tuned and C-type filter. The objective is to reduce the harmonic distortion in an industrial power supply system and discusses the harmonics present on the electric power system of non-linear electric loads. The components of Harmonics are reduced considerably. The Passive filter plays a vital role in the harmonics mitigation for varying non-linear load. The designing of single, double-tuned and C-type filters are proposed based on fundamental frequency, reactive power relationship and quality factor. Analysis on the basis of Simulation results show that the C-type filter designed in this method works better than single and double tuned filter.**

Keywords— Fundamental Frequency, Harmonics distortion, Single Tuned filter, Double Tuned Filter, C-Type Filter.

I. INTRODUCTION

The development of power electronics switches has drastically improved the performance of the electrical drives and other electronic equipment. But as the usage of these switches has increased harmonics. Harmonics are current or voltage with frequencies that are integral multiple of fundamental power. Filter is a circuit that removes the particular harmonic or set of harmonics from the system. The most common type of shunt passive filters used in harmonic mitigation is the single tuned filter which is either a low pass or band pass filter. The double tuned filter can be used to filters two harmonic components simultaneously. The function of Double-tuned filter and two parallel single tuned filter are same as both of them can filter two different frequency harmonics. The performance of C-Type passive filter is better as compared to other filters. The use of tuned filter often results in parallel resonance between filter and the system admittance at a harmonics order below the lower tuned frequency as in single tuned filter or in between tuned filter frequency. There is no problem of parallel resonance on C-Type filter.

II. SINGLE TUNED FILTER

The basic principle of using passive single tuned filter is the simple to design and low cost to implement. The diagram of a single tuned filter is shown in Fig. 1

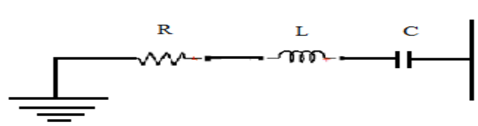

Fig.1 Single tuned filter circuit

The circuit diagram of the filter at fundamental frequency is shown in Fig.2. Reactive power relationship is given by

$$X_C - X_L = \frac{V^2}{kVAR_{filter}} \tag{1.1}$$

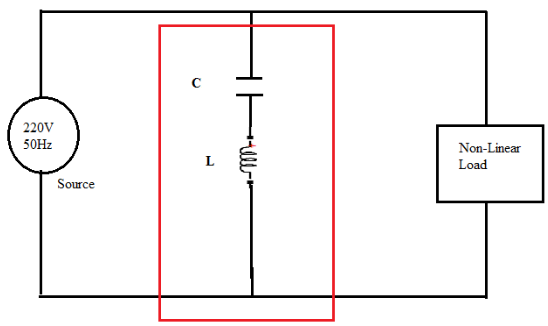

Fig.2 Filter equivalent circuit at fundamental frequency

Since the two component is tuned at third harmonics so,

$$X_L = X_C$$

$$\omega_h^2 = \frac{1}{LC} = (2\pi fh)^2 \tag{1.2}$$

Where, h is the harmonic to which the filter is tuned. The filter resistance R is based on quality factor Q which is a measure of the sharpness of tuning. Mathematically, quality factor is defined as,

$$Q = \frac{1}{R} \times \sqrt{\frac{L}{C}} \tag{1.3}$$

Where V is source voltage
kVAR is reactive power supplied by the filter
X_L and X_C are the inductive and capacitive Reactance
ω_h is angular frequency at tuned harmonics
h is tuned harmonics frequency number
f is fundamental frequency
L, C and R are the filter component

The resistance value may be obtained by selecting an appropriate quality factor value in the range of $20 < Q < 30$.

Simulation Results - A single tuned filter has been designed using following parameters.

V=220 V at 50 Hz
Source inductance = .001 H
$kVAR_{filter}$ = 12 kVAR
Q = 25
Tuned frequency (h) = 3
And the observations are as follows
C=.7mF
L=1.6mH
R=.06Ω
Rectifier load with inductance L= .05H and resistance R=1Ω.

A single tuned filter was designed, and the results were verified in MATLAB. One can clearly see that the amount of third harmonics in the system when filter was not connected was about 37.4% of the source current and the waveform was close to the square wave, but when the filter was connected to the system the third harmonics fell down to 3.34% of source current, and the source waveform was somewhat resembling the sinusoidal waveform. The current wave form was not completely sine wave because or other harmonics presents in the system like 5^{th}, 7^{th}, and so on.

Apart from this single tuned filter have a major problem of parallel frequency, which restricts its practical use. This, parallel frequency come into play when there is small dip in source frequency. In that case instead of eliminating the harmonics from the system, it generates the harmonics. This may also happen due to aging effect, where the parameter value changes as time passes. Fig. 3.8 shows parallel resonance.

III. DOUBLE TUNNED FILTER

Double-tuned filter has a lower cost than the two parallel single tuned filters. Compared to the Single tuned filter with the same performance, double tuned filter has a few advantages such as only one reactor is subjected to full line voltage and smaller space needed. The basic configuration of double tuned filter is shown in Fig. 3.

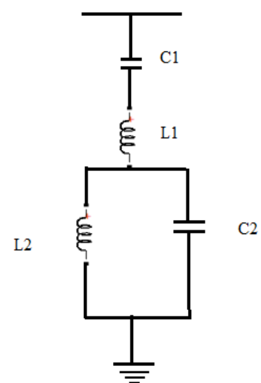

Fig.3 Double tuned filter circuit

Since C_1 and L_1 are tuned at fundamental frequency, only C_2 is responsible for the reactive power supplied by the filter at fundamental frequency. Hence,

$$X_{C2} = \frac{V^2}{kVAR_{filter}} \tag{1.4}$$

Since, C_1 and L_1 are tuned at fundamental frequency one gets,

$$\omega_1^2 = \frac{1}{L_1C_1} = (2\pi f)^2 \tag{1.5}$$

Now C_1, L_1 and C_2 are tuned at frequency say ω_{h1} so,

$$\frac{1}{\sqrt{L_1\left[\frac{C_1C_2}{C_1+C_2}\right]}} = \omega_{h1} \tag{1.6}$$

Simulation results - A double tuned filter has been designed for 220V, 50 Hz system with reactive power of 12 kVAR and the observations are as follows

Assumption made
Source inductance = .001H
Tuned harmonics = 150 Hz and 250 Hz
Rectifier load with inductance L= .05H and resistance R=1Ω
Parameter values

C_2 = .789mF
L_1 = 1.6mH
C_1 = 6.31mF
L_2 =1.6mH
A double tuned filter was designed, and the results were verified in Matlab. The filter designed was able to remove the 3rd and 5th harmonics from the system to an extent. One can clearly see that the amount of third harmonics and fifth harmonics in the system when filter was not connected was about 37.4% and 15.8% of the source current respectively and the waveform was close to the square wave, but when the filter was connected to the system the third harmonics fell down to 25.4% of source current and fifth harmonics to 8.5% of the source current, and the source waveform was resembling the sinusoidal waveform but it was not pure sinusoidal as there was higher order harmonics present in the system but they were not much dominant. So the waveform was not pure sinusoid but was close to sinusoid.

Though this filter was filtering the two harmonics from the system, but its filtering was not as effective as two single tuned filter used together to filter out the two harmonics. It can be observed that, in case of single tuned filter, after filtering the third harmonics content was about 3.34% of source current, where as in case of double tuned filter it was about 25% of source current. Although single tuned filter gave good result but it is not in use because of parallel resonance problem.

IV. C-TYPE FILTER

C-Type filter is the efficient method to eliminate the filter from the system. The configuration of C-type filter is depicted in Fig. 4

A filter was designed for 220V, 50 Hz system with reactive power of 12 kVAR with assumption:

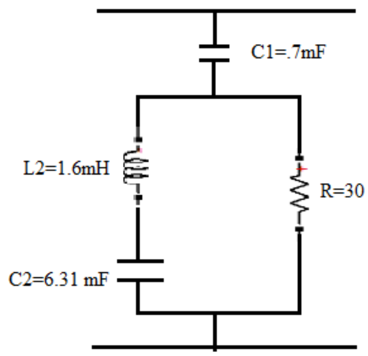

Fig.4 C-Type filter tuned at 3rd harmonics

Source inductance = .001H
Tuned harmonics = 150 Hz
Rectifier load with L= .05H and R=1Ω
And the designed parameter values are

C_1 = .7mF
C_2 =6.31mH
L_2 =1.61mH
R = 30Ω

V. DESIGN AND IMPLEMENTATION

SCHEMATIC DESIGN ON MENTOR GRAPHICS PYXIS 10.1

M1 and M2:- NMOS Transistors W/L ratio = 0.15u/0.13u
M3:- NMOS Transistors W/L ratio = 0.45u/0.13u
M4 and M5:- PMOS Transistor W/L ratio:- 0.15u/0.13u
For DC Analysis:-Voltage, V1- Grounded, Voltage V2 =3.3 V magnitude

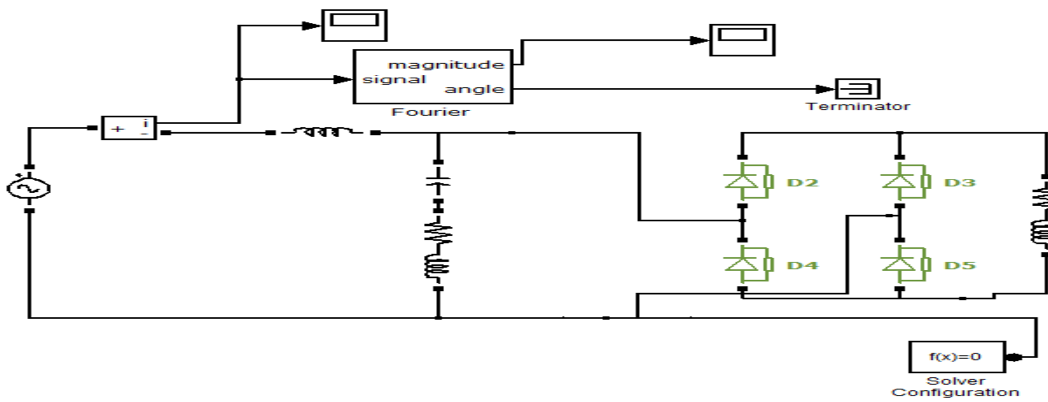

Fig.5 Single tuned circuit in Matlab

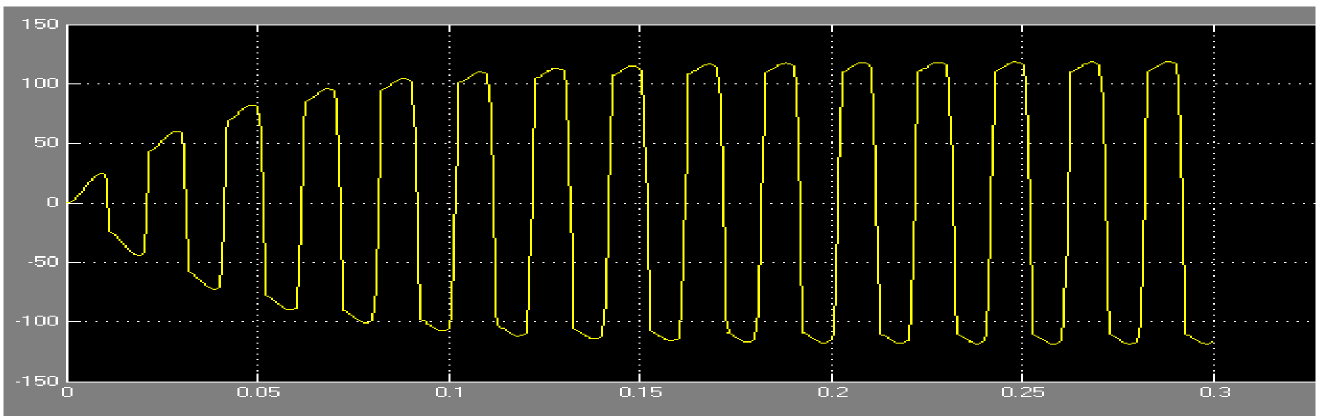

Fig.6 Source current without filter connected to the system of circuit shown in Fig.5.

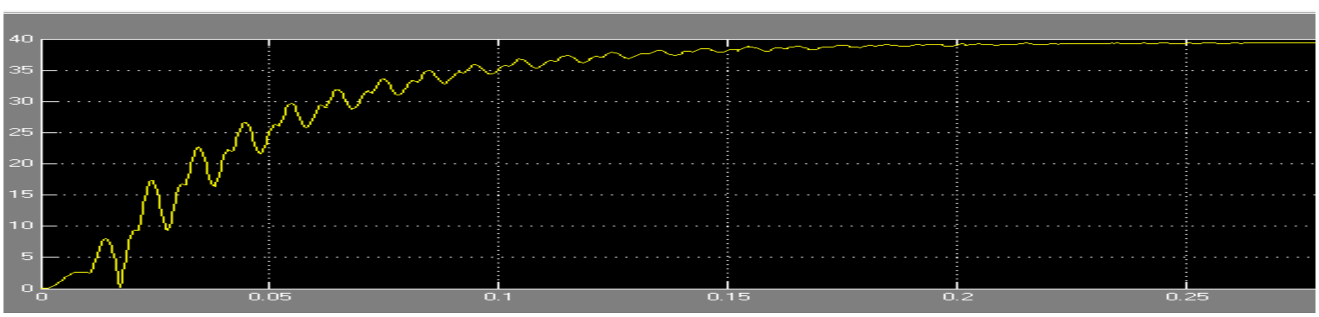

Fig.7 Third harmonics (in rms) component of current waveform shown in Fig. 6

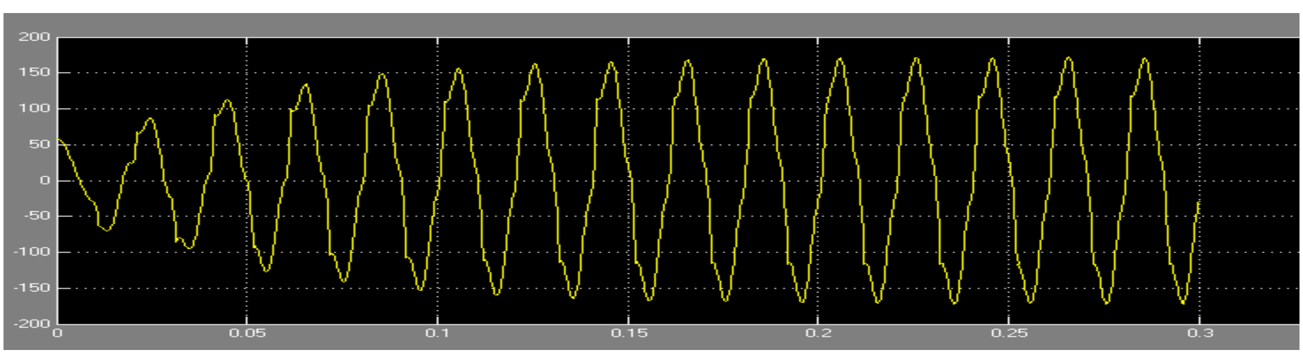

Fig.8 Source current with filter connected to the system of circuit shown in Fig.5

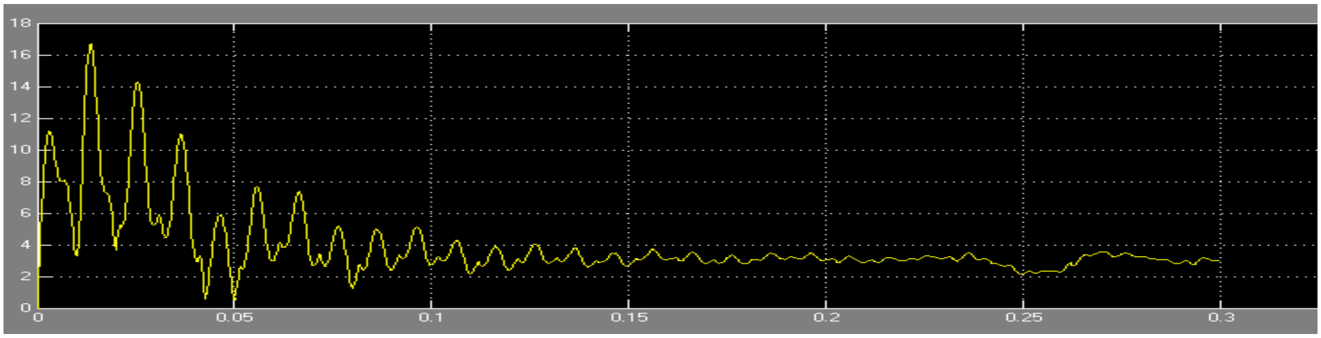

Fig.9 Third harmonics (in rms) component of current waveform shown in Fig.8

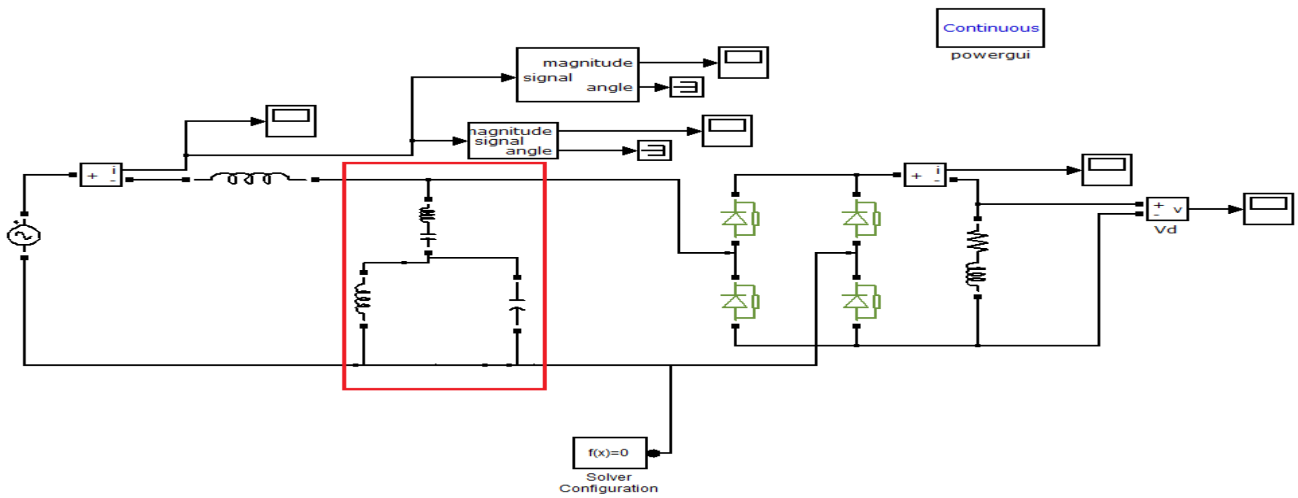

Fig.10 Double Tuned Filter circuit marked within red box

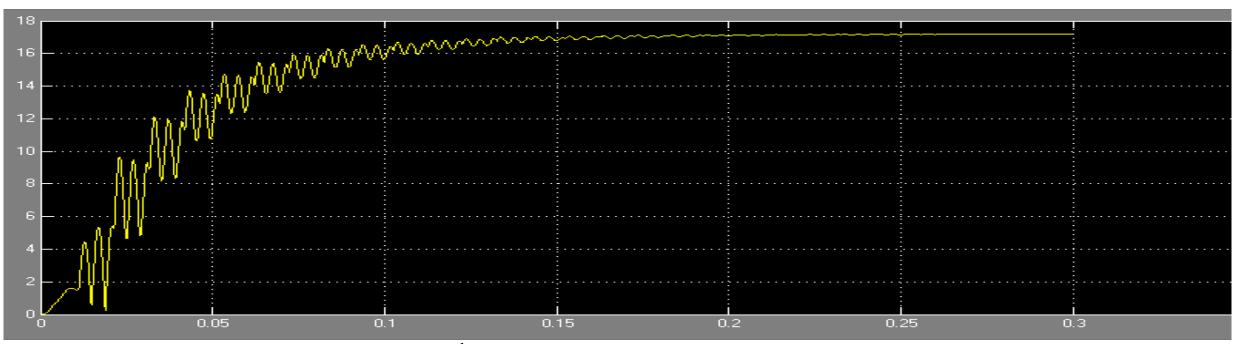

Fig.11 5th harmonics (in rms) in source current

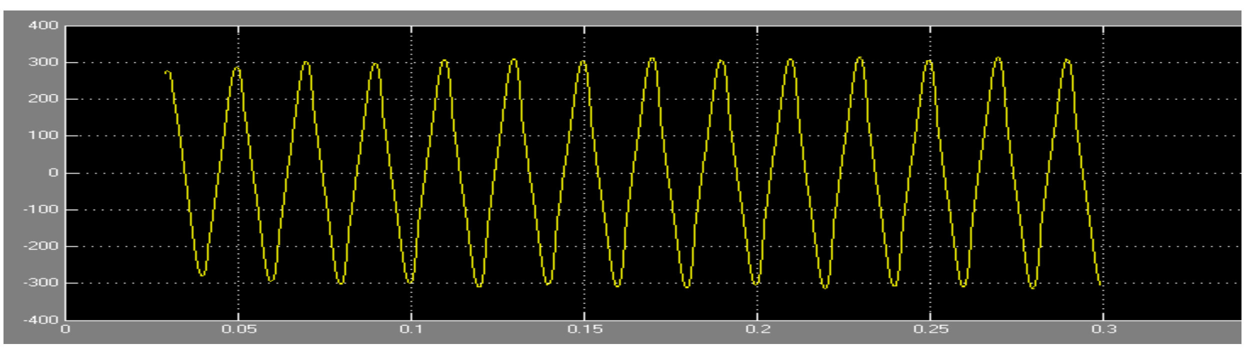

Fig.12 Source current of the system shown in Fig. 10 with filter

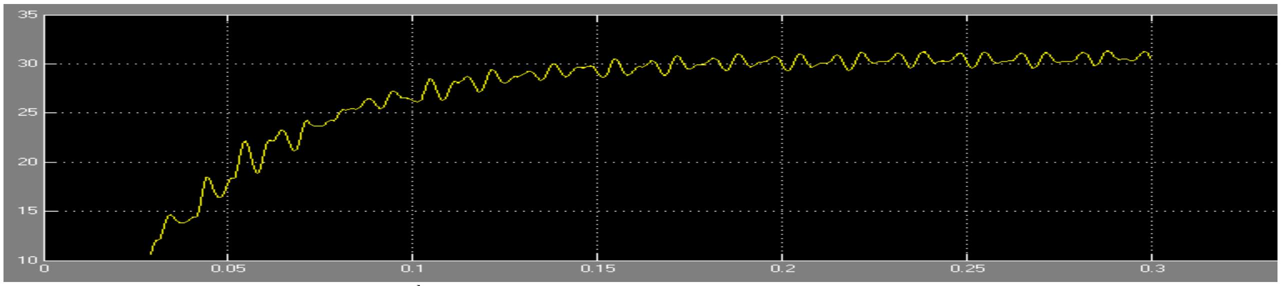

Fig.13 3rd harmonics (in rms) in source current with filter

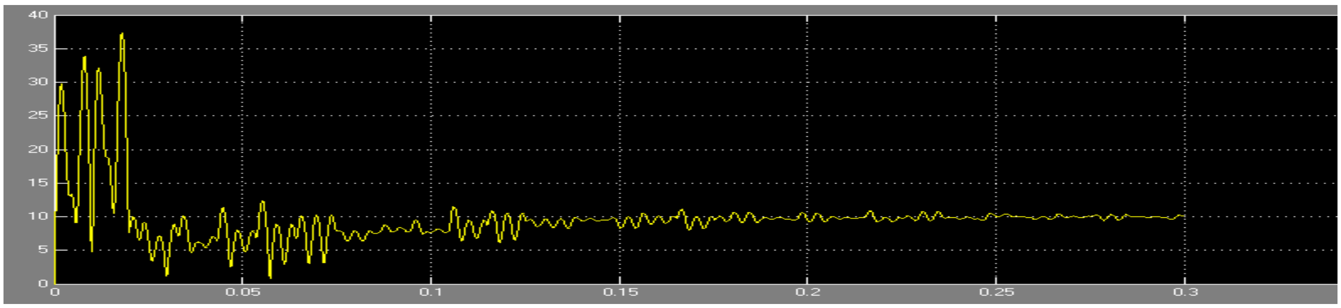

Fig.14 5th harmonics (in rms) in source current with filter

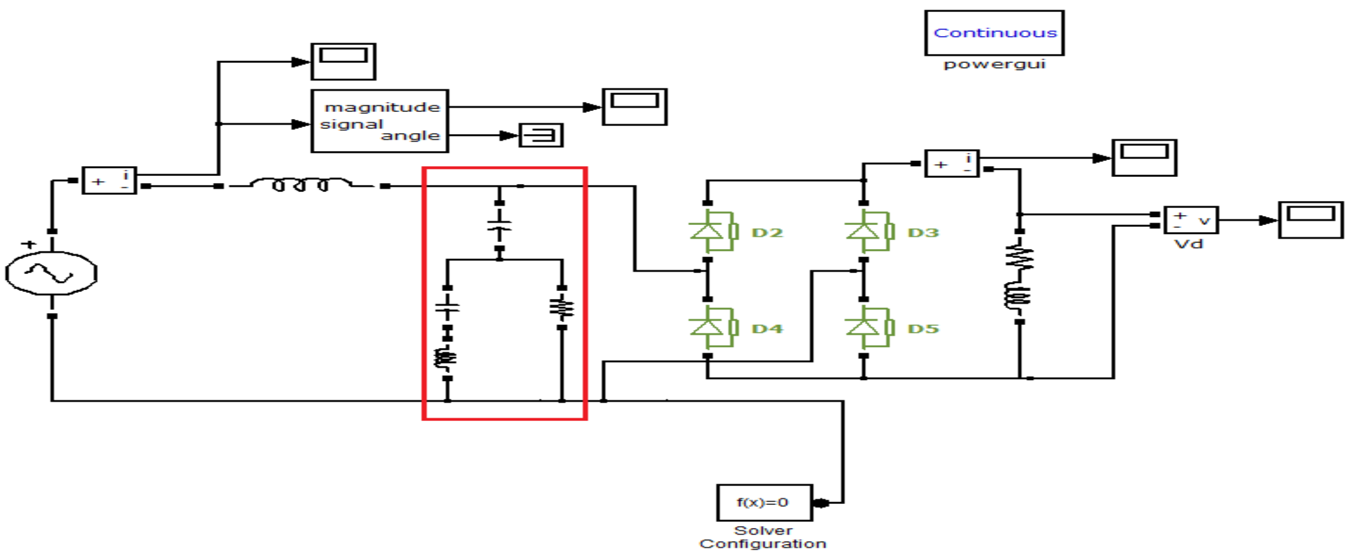

Fig.15 C-Type filters Circuit marked within Red box

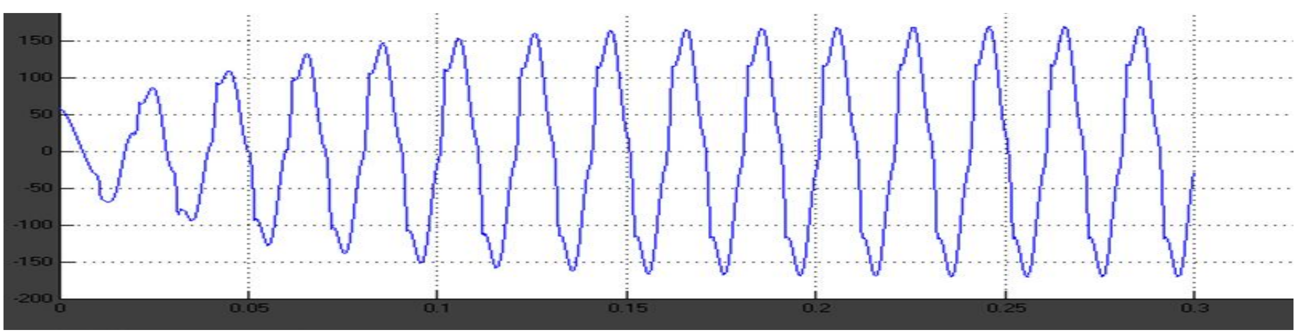

Fig.16 Source current with filter connected to the system

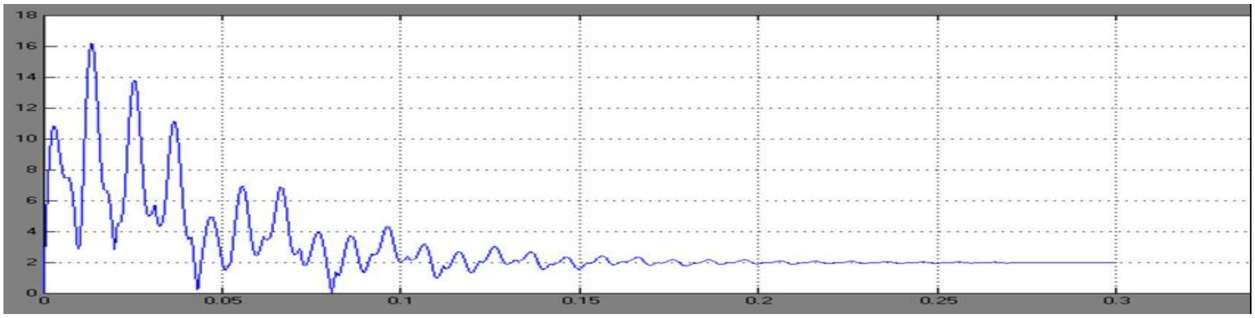

Fig.17 Third harmonics (in rms) component of current waveform

VI. CONCLUSION

A program has been developed to simulate the passive power filter in Matlab. It was found from simulation results that filter were not only eliminating harmonics but were improving power quality of the power system by, which makes the load current almost sinusoidal. This is because still there are smaller orders harmonics present in the system, when seen in small scale these harmonics won't create a problem.

Three harmonics mitigation techniques have been discussed. Few passive filters were designed and its parameters were calculated and performance was analyzed. Of the entire passive filter C-Type filter gave better results. But depending on the need selection is to be done between double tuned passive filter and C-Type filter. C-type filter performance and loading are less sensitive to temperature variation, frequency deviation, component tolerance, loss in capacitors. It provides low impedance for wide spectrum of harmonics. The use of single tuned filter often results in parallel resonance between filter and the system admittance at a harmonics order below the lower tuned frequency as in single tuned filter or in between tuned filter frequency. There is no problem of parallel resonance in C-type filter.

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