Harmonic Measurement and Passive Filter Simulation using MATLAB

D C Bhonsle, Dr R B Kelkar

Abstract--**Power quality is becoming a major concern of today's power system engineers. Harmonics play an important and major roll in deteriorating power quality, called harmonic distortion. Harmonic distortion is measured in terms of THD (Total Harmonic Distortion). This paper presents harmonic field measurement in power distribution network. The specific case study has been conducted at C K Pithawalla college of Engineering and Technology, Surat, Gujarat. It includes non-linear loads such as-personal computer, LCD, laptop, etc. Harmonic measurement was conducted for individual loads. The selected distribution network is simulated using MATLAB software. Simulation and design of passive filter is presented in METLAB for harmonic mitigation. Results of the same are analyzed taking in to account IEEE standards limits for harmonic distortion.**

Index Terms—**Power Quality, Harmonics, Non-linear loads, Passive filter.**

I. Nomenclature

THD_V = Total Harmonic Distortion of voltage
THD_I = Total Harmonic Distortion of current
h = Harmonic Order
n = Total Number of Harmonic Order
V = Voltage in volts
I = Current in amperes
C = Capacitance in farads
L = Inductance in henries
R = Resistance in ohms
1 = Fundamental Component
FFT = Fast Fourier Transform
BW = Bandwidth in H_Z
SCR = Short Circuit ratio
V_f = Forward voltage

II. Introduction

NOWADAYS, power quality has become a great concern for both utilities and customers. With the increasing use of non-linear load being connected to the power system, more studies are needed. The problems associated with high harmonic content in the power system do not only result in the poor quality of supply but also the operation of the system will get affected. The major sources of harmonics are from the three categories of equipment: power system equipments, industrial loads and domestic loads. Harmonic currents are generated to a small extent and low distortion level by generation, transmission and distribution equipments and to a larger extent by the industrial and domestic loads [1-5].

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III. Harmonic field measurement

Harmonic field measurement is done to verify the degree of severity of harmonic distortion due to domestic non-linear loads in the distribution system [9-11]. There are number of solid state controlled non-linear equipments are used for domestic application such as electronic fan regulator, personnel computer, printer, etc. These non-linear loads inject harmonic currents in the network thus distorting supply voltage.

In carrying out harmonic measurement at Faculty of Electrical Engineering Department of C. K. Pithawalla Collage of Engineering and Technology, Surat, six types of domestic application were selected. All the measurements are made at 230 V using Yokogawa make clamp on type Power Analyzer (200 A, 600 V). Harmonic spectrum for each load is plotted showing magnitude of each harmonic frequency that makes up a distorted waveform. The magnitude of each harmonic frequency can be expressed as a percentage of fundamental. Total harmonic distortion is defined from harmonic spectrum as the ratio of the RMS sum of all harmonic frequencies to the RMS value of the fundamental.

Mathematically THD is expressed by the following equations [6-9]:

$$THD_V = \frac{\sqrt{(\sum_{h=2}^{n} V_h)^2}}{V_1} \tag{1}$$

$$THD_I = \frac{\sqrt{(\sum_{h=2}^{n} I_h)^2}}{I_1} \tag{2}$$

A. Electronic Fan Regulator

The result from measurement of voltage harmonic spectrum and current harmonic spectrum of electronic fan regulator are shown in Fig. 1 and Fig. 2.

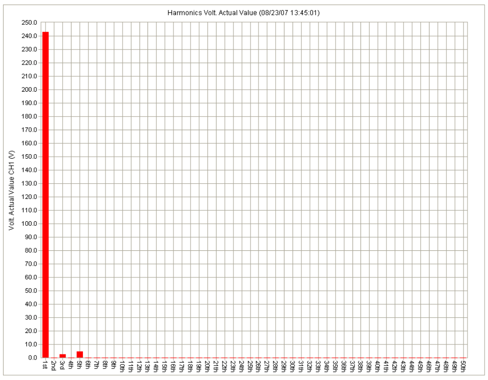

FIG. 1 VOLTAGE HARMONIC SPECTRUM

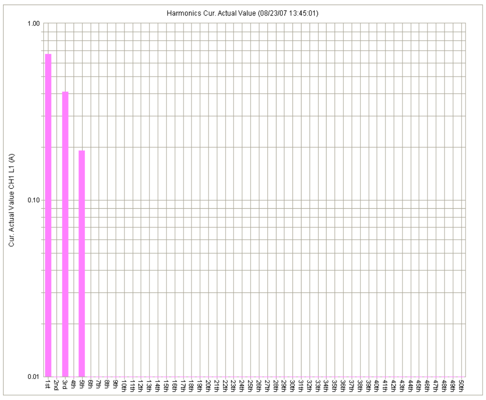

FIG. 2 CURRENT HARMONIC SPECTRUM

Total harmonic distortion for voltage and current can be calculated for electronic fan regulator using (1) and (2).

THD_V =2.2 %

THD_I =97.05 %

B. Personal Computer

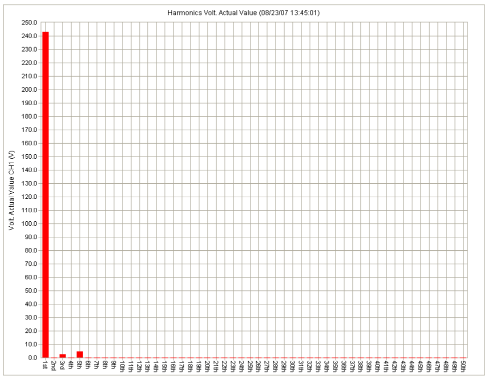

FIG. 3 VOLTAGE HARMONIC SPECTRUM

Similarly harmonic spectrum of personal computer for voltage and current are shown in Fig. 3 and Fig. 4 respectively. 3^{rd} and 5^{th} harmonics are predominant in current taken by personal computer.

Total harmonic distortion are calculated,

THD_V =2.13 %

THD_I =67.44 %

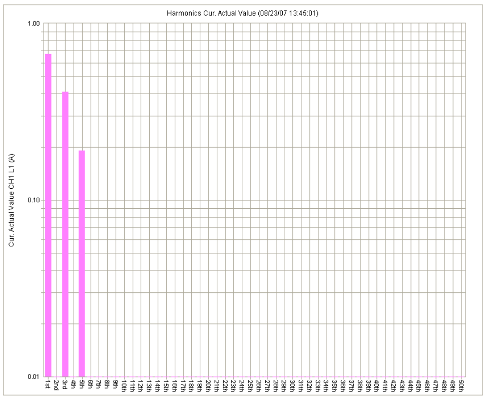

FIG. 4 CURRENT HARMONIC SPECTRUM

C. Laptop

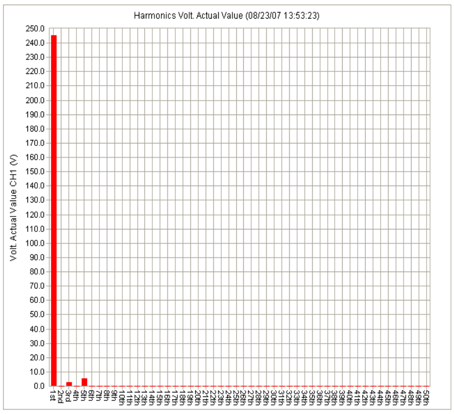

FIG. 5 VOLTAGE HARMONIC SPECTRUM

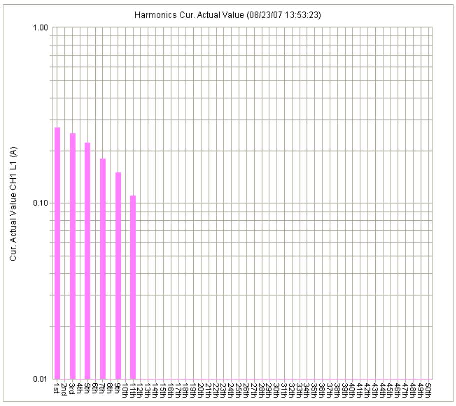

FIG. 6 CURRENT HARMONIC SPECTRUM

Current harmonic spectrum of laptop represents richness of harmonics present-3^{rd}, 5^{th}, 7^{th}, 9^{th} &11^{th}. THD calculated for voltage and current are,

THD_V =2.44 %

THD_I =156.2 %

D. LCD Projector

Total harmonic distortion for LCD projector is,

THD_V =1.68 %

THD_I =12.19 %

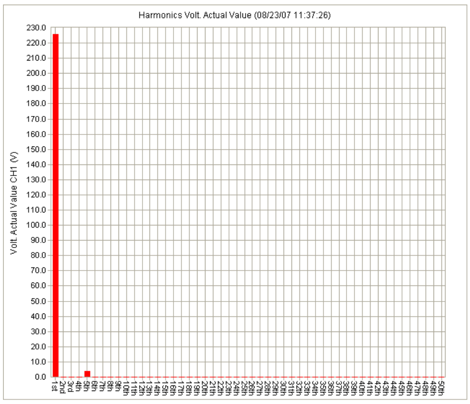

FIG. 7 VOLTAGE HARMONIC SPECTRUM

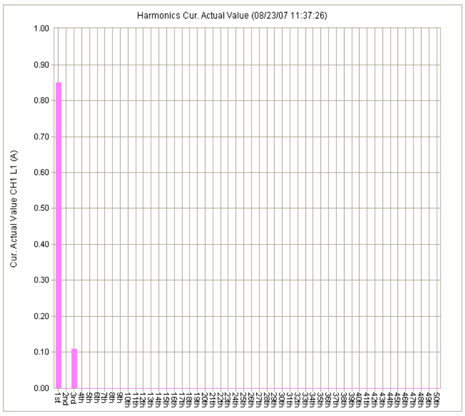

FIG. 8 CURRENT HARMONIC SPECTRUM

IV. SUMMARY

Sr. No.	Non-linear load	THD_V %	THD_I %
1	Electronic Fan Regulator	2.13	67.44
2	Laptop	2.44	156.2
3	Fan Regulator	2.2	97.05
4	LCD Projector	1.68	12.9

FIG. 9 VOLTAGE AND CURRENT HARMONIC DISTORTION OF DOMESTIC NON-LINEAR LOADS

The IEEE 519-1992 [12] has imposed limits on total harmonic distortion (THD), as shown in appendix. Fig. 9 shows that voltage distortion limits of non-linear loads are within limits. Current harmonic distortion ranges from 12.9 % to 156.2 %.

V. HARMONIC SIMULATION

The sources of harmonic can be simulated using MATLAB 7.2 Math Works 2006. Full wave Diode Bridge feeding a capacitor and a resistance in parallel is designed to simulate a non-linear load as shown in Fig. 10.

Standard FFT package of MATLAB is used to plot voltage, current harmonic spectrum and to calculate THD of the same. The results are shown in Fig. 11. While analyzing current harmonic spectrum of simulated non-linear load, it found that 3rd, 5th and 7th odd harmonics are predominant. The subsequent subsection describes the procedure for designing single tuned passive filter for elimination of above said harmonics.

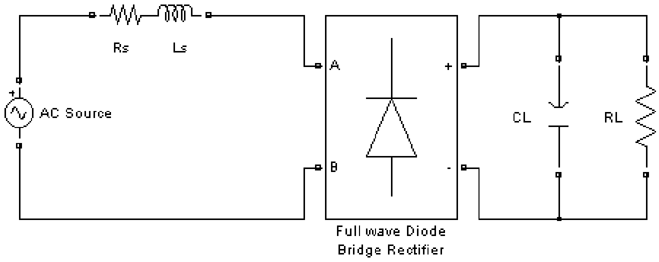

FIG. 10A NON-LINEAR LOAD SIMULATION USING MATLAB

VI. DESIGN OF SINGLE TUNED PASSIVE FILTER

The single tuned filter is designed to trap 3rd, 5th and 7th harmonics by adding reactor with $X_L = X_C$ at the tuned frequency $(n \times f)$. The data required for the single tuned passive filter and the required procedural steps are described below:

A. Data required for the design:

1. Reactive power consumed : Q in VA
2. Supply Voltage : V_S in Volts
3. Supply frequency : f in H_Z
4. Natural Frequency : f_n in H_Z
5. Harmonic order : h in Number
6. Quality Factor : Q_L in Number

B. Procedural steps:

1. $$X_C = \frac{V_S{}^2}{Q} \cdot \frac{h^2}{(h^2 - 1)}$$
2. $$C = \frac{1}{(2 \times \pi \times f \times X_C)}$$
3. $$X_L = \frac{X_C}{h^2}$$
4. $$L = \frac{X_L}{(2 \times \pi \times f)}$$
5. $$R = \frac{h \times X_L}{Q_L}$$
6. $$BW = \frac{f_n}{Q_L}$$

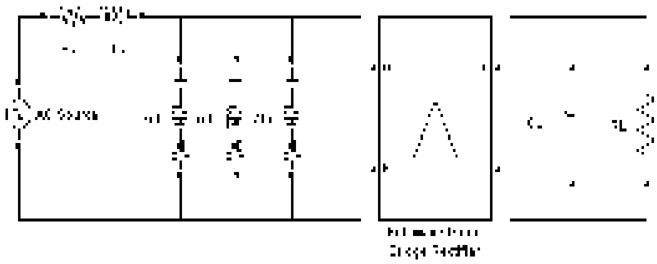

FIG. 10B SINGLE TUNED PASSIVE FILTERS FOR 3RD, 5TH AND 7TH HARMONIC

Following above said procedural steps, three single tuned passive filters are designed to take care 3rd, 5th and 7th harmonics and implemented in MATLAB with the simulated diode bridge non-linear load shown as shown in Fig. 10B. The FFT analysis with and without passive filter is compared in the fore coming section.

VII. RESULTS

Fig. 11 & Fig. 15 show the load current and load voltage before passive filter installation, Fig. 13 & Fig. 17 show harmonic spectrum of load current and load voltage before passive filter installation respectively.

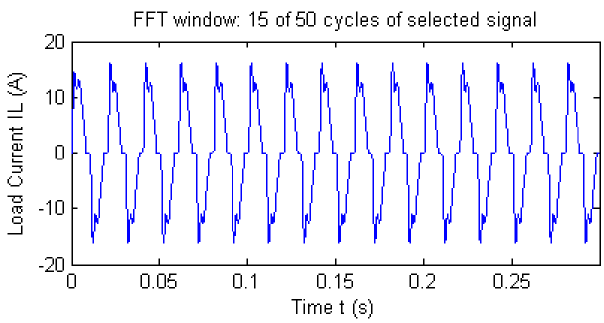

FIG. 11 LOAD CURRENT WITHOUT SINGLE TUNED PASSIVE FILTER

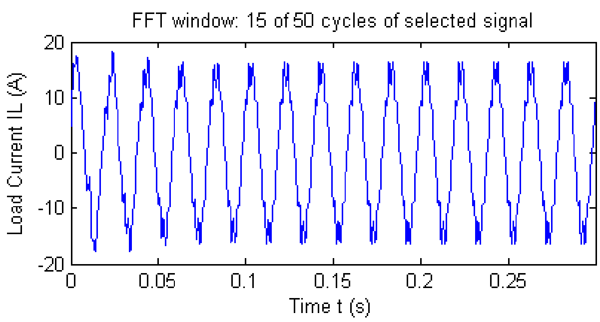

FIG. 12 LOAD CURRENT WITH SINGLE TUNED PASSIVE FILTER

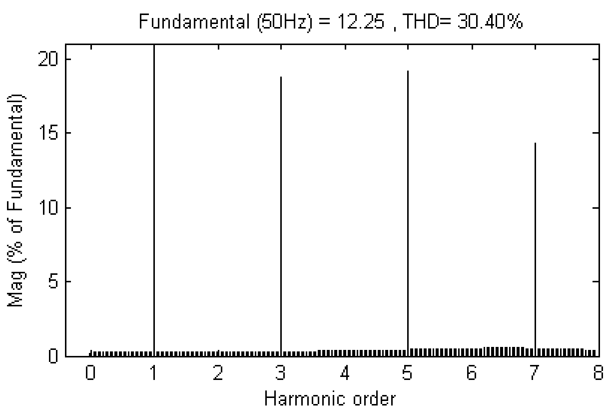

FIG. 13 CURRENT HARMONIC SPECTRUM WITHOUT SINGLE TUNED PASSIVE FILTER

The current harmonic distortion found is 30.40 %. Individual harmonic order THD is shown in the Fig. 25 which shows that IEEE limits for current harmonic distortion limits are violated.

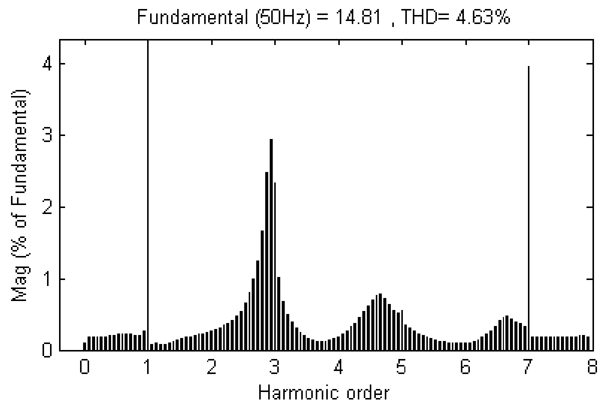

FIG. 14 CURRENT HARMONIC SPECTRUM WITH SINGLE TUNED PASSIVE FILTER

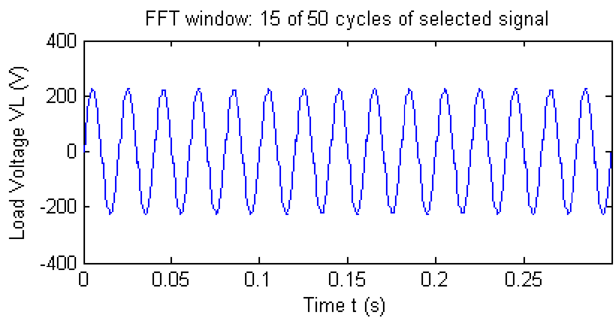

FIG. 15 LOAD VOLTAGE WITHOUT SINGLE TUNED PASSIVE FILTER

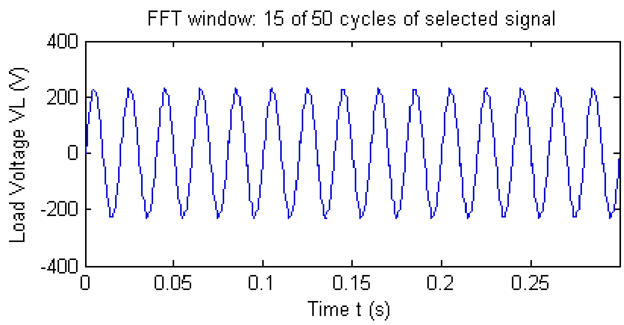

FIG. 16 LOAD VOLTAGE WITH SINGLE TUNED PASSIVE FILTER

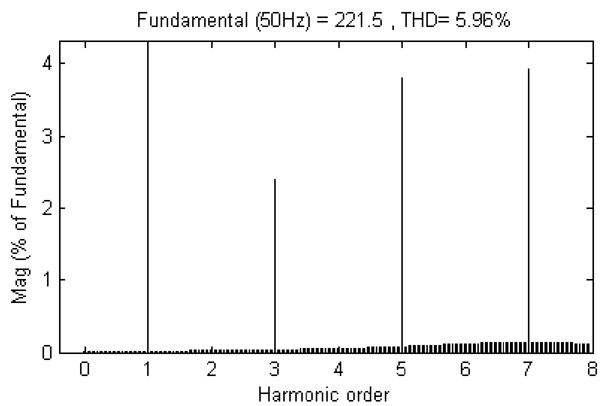

FIG. 17 VOLTAGE HARMONIC SPECTRUM WITHOUT SINGLE TUNED PASSIVE FILTER

The voltage harmonic distortion found is 5.96 %. Individual harmonic order THD is shown in the Fig. 26 which shows that IEEE limits for voltage harmonic distortion limits are violated.

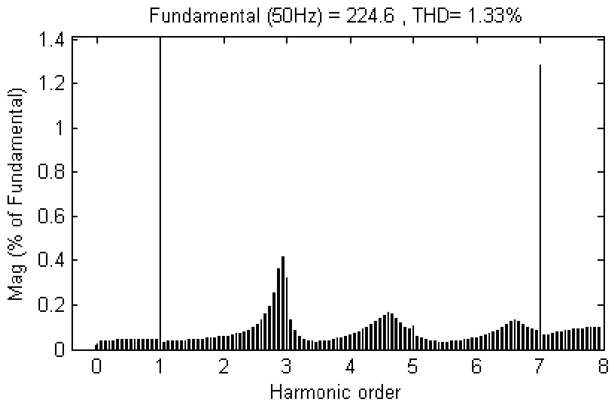

FIG. 18 VOLTAGE HARMONIC SPECTRUM WITH SINGLE TUNED PASSIVE FILTER

Fig. 12 & Fig. 16 show the load current and load voltage after passive filter installation, Fig. 14 & Fig. 18 show harmonic spectrum of load current and load voltage after passive filter installation respectively.

FFT window selected for 15 of 50 cycles of selected current and voltage signals. Total harmonic distortion in current was reduced to 4.63 % from 30.40 % after passive filter installation. Whereas voltage harmonic distortion is reduced to 1.33 % from 5.96 % after passive filters installation.

Moreover considerable reduction in the total harmonic distortion in the respective order of harmonic is noticed, tabulated at the end of this section, shown in Fig. 25 & Fig. 26.

Fig. 19 describes almost zero impedance offered for the 3rd, 5th and 7th ordered harmonics.

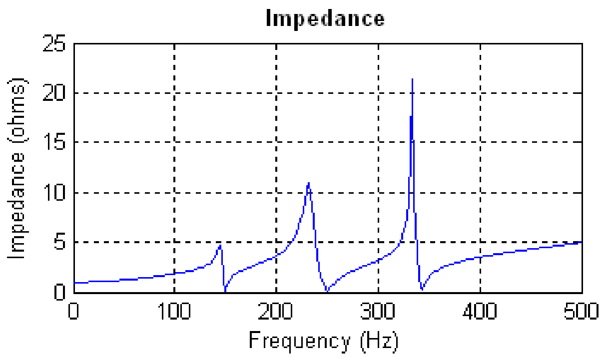

FIG. 19 IMPEDANCE AND V/S FREQUENCY OF PASSIVE FILTER

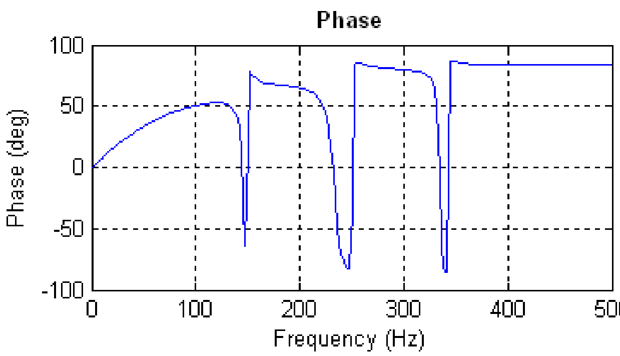

FIG. 20 PHASE V/S FREQUENCY OF PASSIVE FILTER

Fig. 20 shows phase relationship at the 3rd, 5th and 7th harmonic frequencies.

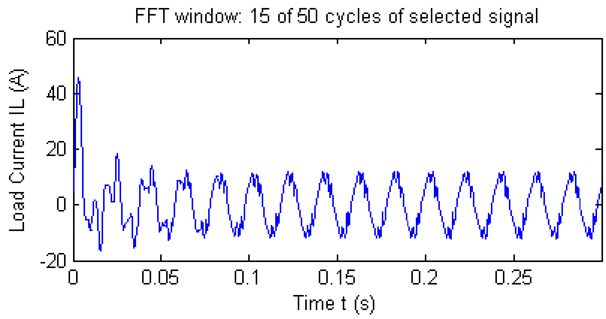

FIG. 21 LOAD CURRENT WITH SINGLE TUNED PASSIVE FILTER UNDER CHANGED LOAD CONDITION

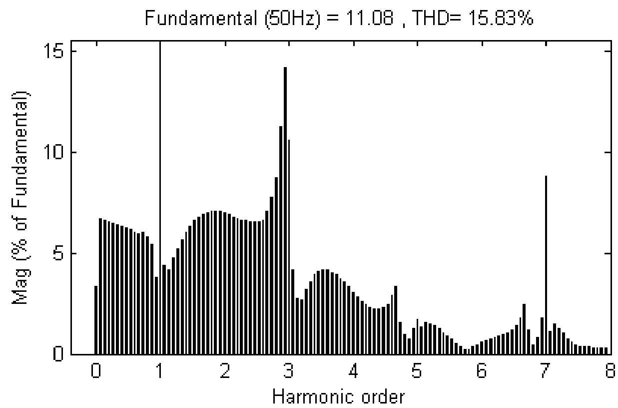

FIG. 22 CURRENT HARMONIC SPECTRUM WITH SINGLE TUNED PASSIVE FILTER UNDER CHANGED LOAD CONDITION

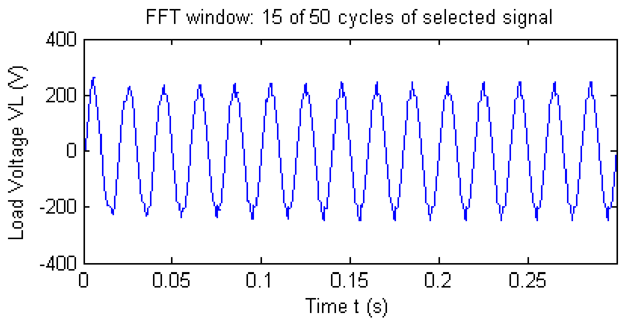

FIG. 23 LOAD VOLTAGE WITH SINGLE TUNED PASSIVE FILTER UNDER CHANGED LOAD CONDITION

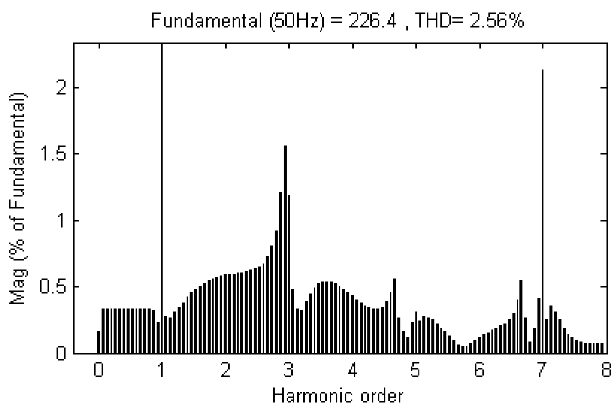

FIG. 24 LOAD VOLTAGE HARMONIC SPECTRUM WITH SINGLE TUNED PASSIVE FILTER UNDER CHANGED LOAD CONDITION

Single tuned passive filters result in detuning subjected to load change. In the presented simulation load current is changed from 14.81 A to 11.08 A by changing load circuit parameters. Fig. 21 & Fig. 23 represent the load current and load voltage waveforms, Fig. 22 & Fig. 24 shows harmonic spectrum after load change being applied. It shows that the current harmonic distortion increases to 15.83 % from 4.63 % and voltage harmonic distortion reaches 2.56 % from 1.33 % as shown in Fig. 27.

	Before PF	After PF	% Reduction
3rd	2.3 A	0.34 A	85.21 A
5th	2.34 A	0.08 A	96.58 A
7th	1.75 A	0.59 A	66.28 A
THD	30.40 %	4.63 %	84.76

FIG. 25 IMPROVEMENT IN LOAD CURRENT THD

	Before PF	After PF	% Reduction
3rd	5.3 V	0.73 V	86.22
5th	8.42 V	0.23 V	97.26
7th	8.67 V	1.28 V	66.78
THD	5.96 %	1.33 %	77.68

FIG. 26 IMPROVEMENT IN LOAD VOLTAGE THD

	Load Current in %	Load Voltage in %
3rd	10.53	1.19
5th	1.70	0.31
7th	8.81	2.31
THD	15.83	2.56

FIG. 27 CHANGE IN LOAD CURRENT AND LOAD VOLTAGE DUE TO DETUNNING

VIII. CONCLUSION

Harmonic is the predominant power quality issue. Non-linear domestic loads connected in the distribution system inject considerable current harmonics in the supply system resulting in THD_I ranging from 12.9 % to 156.2 % which violates the limits specified by IEEE 519 for current harmonic distortion.

Filtering is one of the solutions to prevent the harmonic from entering the rest of the system. Implementation of single tuned passive filter taking care of 3rd, 5th and 7th harmonic, suppresses the THD_I by 84.76 % and THD_V by 77.68 %.

Changed system configuration changes the harmonic profile of the system resulting in detuning, stating the limitation of passive filters.

IX. APPENDIX

A. Harmonic Voltage limits by IEEE 519

Bus Voltage in KV	THD_V in %
69 & above	5.0
115-161	2.5
>161	1.0

B. Harmonic Current limits by IEEE 519

SCR	THD_I in %
<20	5.0
20-50	8.0
50-100	12.0
11-15	20.0

C. Designed Circuit Parameters used for simulation of non-linear load

V_S	230 Volts	C_L	100 µF
f	50 H_Z	R_L	20 Ω
R_S	1 Ω	V_f	0.8 Volts
X_S	2.2 mH		

D. Designed Circuit Parameters used for simulation of Passive Filters

For 3rd Harmonic		For 5th Harmonic		For 7th Harmonic	
R Ω	0.1	R Ω	0.033	R Ω	0.017
C µF	42.67	C µF	14.2	C µF	29.1
L mH	26.4	L mH	28.51	L mH	7.4

X. ACKNOWLEDGMENT

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XI. REFERENCES

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