**Abstract**—Power quality is becoming a major concern of today’s power system engineers. Harmonics play an important and major role 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 MATLAB 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

\[
THD_V = \frac{\sum_{h=2}^{n} V_h}{V_1}
\]

\[
THD_I = \frac{\sum_{h=2}^{n} I_h}{I_1}
\]

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.

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]:
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**

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,

\[ THD_v = 2.13\% \]
\[ THD_i = 67.44\% \]

**C. Laptop**

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,

\[ THD_v = 1.68\% \]
\[ THD_i = 12.19\% \]
IV. SUMMARY

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Non-linear load</th>
<th>THD, V %</th>
<th>THD, I %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electronic Fan Regulator</td>
<td>2.13</td>
<td>67.44</td>
</tr>
<tr>
<td>2</td>
<td>Laptop</td>
<td>2.44</td>
<td>156.2</td>
</tr>
<tr>
<td>3</td>
<td>Fan Regulator</td>
<td>2.2</td>
<td>97.05</td>
</tr>
<tr>
<td>4</td>
<td>LCD Projector</td>
<td>1.68</td>
<td>12.9</td>
</tr>
</tbody>
</table>

FIG. 7 VOLTAGE HARMONIC SPECTRUM

FIG. 8 CURRENT HARMONIC SPECTRUM

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.

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 HZ
4. Natural Frequency : \( f_n \) in HZ
5. Harmonic order : \( h \) in Number
6. Quality Factor : \( Q_L \) in Number

B. Procedural steps:
1. \( X_C = \frac{V_S^2}{Q} \frac{h^2}{(h^2 - 1)} \)
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. \( BW = \frac{f_n}{Q_L} \)
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.

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.

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

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.

<table>
<thead>
<tr>
<th>Load Current in %</th>
<th>Load Voltage in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3rd</td>
<td>10.53</td>
</tr>
<tr>
<td>5th</td>
<td>1.70</td>
</tr>
<tr>
<td>7th</td>
<td>8.81</td>
</tr>
<tr>
<td>THD</td>
<td>15.83</td>
</tr>
</tbody>
</table>

FIG. 26 IMPROVEMENT IN LOAD VOLTAGE THD

<table>
<thead>
<tr>
<th>Before PF</th>
<th>After PF</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>3rd</td>
<td>2.3 A</td>
<td>0.34 A</td>
</tr>
<tr>
<td>5th</td>
<td>2.34 A</td>
<td>0.08 A</td>
</tr>
<tr>
<td>7th</td>
<td>1.75 A</td>
<td>0.59 A</td>
</tr>
<tr>
<td>THD</td>
<td>30.40 %</td>
<td>4.63 %</td>
</tr>
</tbody>
</table>

VIII. CONCLUSION

Harmonic is the predominant power quality issue. Nonlinear 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 $THD_r$ 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

<table>
<thead>
<tr>
<th>Bus Voltage in KV</th>
<th>$THD_i$ in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>69 &amp; above</td>
<td>5.0</td>
</tr>
<tr>
<td>115-161</td>
<td>2.5</td>
</tr>
<tr>
<td>&gt;161</td>
<td>1.0</td>
</tr>
</tbody>
</table>

B. Harmonic Current limits by IEEE 519

<table>
<thead>
<tr>
<th>SCR</th>
<th>$THD_i$ in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>5.0</td>
</tr>
<tr>
<td>20-50</td>
<td>8.0</td>
</tr>
<tr>
<td>50-100</td>
<td>12.0</td>
</tr>
<tr>
<td>11-15</td>
<td>20.0</td>
</tr>
</tbody>
</table>

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

| $V_s$ | 230 Volts |
| $C_L$ | 100 µF    |
| $f$   | 50 Hz     |
| $R_L$ | 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

<table>
<thead>
<tr>
<th>For 3rd Harmonic</th>
<th>For 5th Harmonic</th>
<th>For 7th Harmonic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R$</td>
<td>0.1 Ω</td>
<td>0.033 Ω</td>
</tr>
<tr>
<td>$C$</td>
<td>42.67 µF</td>
<td>14.2 µF</td>
</tr>
<tr>
<td>$L$</td>
<td>26.4 mH</td>
<td>28.51 mH</td>
</tr>
</tbody>
</table>

X. ACKNOWLEDGMENT

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XI. REFERENCES

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Standards: