3.1 INTRODUCTION

The use of harmonic filters on low and medium voltage industrial systems did not occur until the early 80's. Different types of passive filters are single tuned, high pass filters, third order filters and C type filters (as shown in Fig.3.1).

However single tuned or high pass filters are generally used in industries. They have been used to improve Power factor and to absorb harmonics in Power Systems because of low cost, simplicity and efficiency.

Harmonic filters function by providing a low impedance path for harmonic currents generated by non-linear loads as shown in Fig.3.2 (i.e.), the filter impedance at the tuned frequency is much less than the system/source impedance.
Fig. 3.1 Types of Harmonic Filters

- **Series Tuned Filter Bank**
- **Second Order or High Pass Filter**
- **Third Order Filter**
- **C-Type Filter**
Fig 3.2(a) Simplified System Design

Fig 3.2(b) Equivalent Circuit of System Shown in Fig 3.2 (a)
3.2 IEEE STANDARD 519-1992 CURRENT LIMITS


1. Harmonic current limits are specified for individual customers. These are evaluated at point of Common Coupling (PCC) between customers and power system.
2. Harmonic voltage limits are specified for the whole system and provide an indication of power quality that the customer can expect.

The revised version of IEEE Standard 519-1992 defines harmonic current limits for individual customers (Table I). These are designed to limit the injection of harmonic currents into power system so that the resulting voltage distortion will be acceptable to all customers.

In order to evaluate a facility regarding these limits few terms are defined as follows:

1. Point of common coupling (PCC): This is the location where the harmonic currents are evaluated. It will probably be determined by the utility.
2. Average maximum demand load current (I_L): All harmonic current limits are given as percent of this value. It is defined as average of the monthly maximum demands for 12 months.
3. Short circuit ratio (I_sc): This the ratio of the short circuit current at PCC to average maximum demand load current (I_L). A strong system with respect to the customer size will result in higher values for the SCR.
Table 3.1 IEEE Standard 519-1992 Harmonic Current Limits

<table>
<thead>
<tr>
<th>SCR</th>
<th>&lt; 11</th>
<th>11 ≤ h &lt; 17</th>
<th>17 ≤ h &lt; 23</th>
<th>23 ≤ h &lt; 35</th>
<th>35 ≤ h</th>
<th>THD</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>4.0</td>
<td>2.0</td>
<td>1.5</td>
<td>0.6</td>
<td>0.3</td>
<td>5.0</td>
</tr>
<tr>
<td>20&lt;50</td>
<td>7.0</td>
<td>3.5</td>
<td>2.5</td>
<td>1.0</td>
<td>0.5</td>
<td>8.0</td>
</tr>
<tr>
<td>50&lt;100</td>
<td>10.0</td>
<td>4.5</td>
<td>4.0</td>
<td>1.5</td>
<td>0.7</td>
<td>12.0</td>
</tr>
<tr>
<td>100&lt;1000</td>
<td>12.0</td>
<td>5.5</td>
<td>5.0</td>
<td>2.0</td>
<td>1.0</td>
<td>15.0</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>15.0</td>
<td>7.0</td>
<td>6.0</td>
<td>2.5</td>
<td>1.4</td>
<td>20.0</td>
</tr>
</tbody>
</table>


Note: Even harmonics are limited to 25 percent of the odd harmonic limits shown above.

3.3 METHODOLOGY FOR COMPUTATION OF DISTORTION TO MEET IEEE 519-1992 STANDARD

Step 1: Individual current harmonic distortion at each dedicated bus can be computed by using manufacturer-supplied computer programs or measuring instruments. The values are reported in per unit.

Step 2: Once the harmonics currents are estimated at each dedicated bus, total harmonic currents at point of common coupling for each individual harmonic can be computed as follows:

\[ I_{d_a} = I_{h_B} + I_{h_C} + I_{h_D} + \ldots \quad h = 5,7,11,13 \]
In other words, each individual harmonic current at PCC is the sum of harmonic current contributions for each dedicated bus. Similarly, the load current at PCC is given by the following:

$$\text{IL}_A = \text{IL}_B + \text{IL}_C + \text{IL}_D + \ldots$$

The best way to estimate the maximum demand load current at PCC is to compute the connected load for each branch feeder and multiply by a demand factor to obtain feeder demand.

**Step 3:** Choose a base MVA and base kV for the system. Use the following equations to compute total current and voltage harmonic distortions at PCC and any other desired points.

$$V_{\text{THD}} = \sqrt{\sum (V_h^2)/V_i^2} \quad (3.1)$$

$$I_{\text{THD}} = \sqrt{\sum I_h^2 / I_i^2} \quad (3.2)$$

Values of individual and total voltage and current harmonic distortion can be computed with the above equations and compared with the IEEE limits.

Once the short circuit ratio is known the IEEE limits can be computed as specified in Table 3.1.

### 3.4 ELECTRICAL TRANSIENT ANALYSIS PROGRAM

The load flow analysis of the system under study was performed using the Electromagnetic Transient Analysis Program. The average power factor of the system obtained by field measurements are identical with that
obtained using the ETAP. Hence filters were designed to improve power factor and reduce harmonic distortion.

3.4.1 Introduction

ETAP power station is a fully graphical electrical transient analyzer program that can run under Microsoft Windows NT, Microsoft Windows 95, and Microsoft Windows 98 environment. Power Station allows you to work directly with graphical one-line diagrams and underground cable race ways systems. The Program has been designed according to three key concepts

- Virtual Reality Operations

  The Program operation resembles real electrical operation closely as possible.

- Total Integration Of Data

  Power Station combines the electrical, mechanical, the physical attributes of the system elements in the same database. Thus integrating the data entry for the same element.

- Simplicity in data entry

  Data Editors speed data entry by requiring the minimum data for a particular study.
3.4.2 Features

3.4.2.1 System Modelling

- Graphical user interface
- Total Integration of data
- Simplicity in data entry
- Multiple loading conditions
- User access control and data validation

In Other Data Base Connectivity are the facilities available to
- Utilize any database for which an ODBC Driver exists
- Integrate other project data into same database

3.4.2.2 One – line diagram elements

- Motor Operated valve (MOV)
- Capacitor
- Contactor
- Single pole, Single throw switch
- Single pole double throw switch
- Static load
- Synchronous Capacitor
- Fuse
- Synchronous Generator
- Bus / Node
- Current transformer
- Transmission Line
• Composite motors
• Cable
• Reactor
• Lumped load

3.4.2.3 Transformer typical data

• Typical Impedance Data and X/R ratio based on transformer BIL level, MVA and KV rating

3.4.2.4 Power Plot Module

• Graphical User Interface
• Complete Integration with Power Station
• Motor Starting Curve
• Transformers
• Cables
• Protective devices
• Motors
• One Line Diagrams

3.5 FILTER DESIGN BASED ON IEEE STANDARD 519-1992

Harmonic analysis and filter design study of the four industries were completed using ETAP package. These studies can be based on power factor improvement or power system characteristics. The program was able to perform a steady stable analysis on a model of the system when arc furnace or induction furnace act as harmonic source. The harmonic currents were injected at the
location of the inductor furnace load or arc furnace load into the system and plotting the impedance or phase angle with each frequency produces a frequency scan of the system which will show any system resonance. The program will also show the harmonic distortion at each load point.

From the analysis of Harmonic measurements, it was observed that harmonics of the order 3, 5, 7 were found predominant. A software program was written to calculate the filter components (L and C) of the passive shunt filter.

3.5.1 Design Equations

The impedance of the filter branch is given by

\[ Z = R + j (\omega L - 1/\omega C) \]  

Resonance occurs when the imaginary part is equal to zero, at which time the impedance is limited by the value of R. The frequency for which the filter is tuned is given by the value that results in series resonance. This frequency is given as

\[ f = \frac{1}{2\pi\sqrt{LC}} \]

Defining the harmonic \( n \) as the frequency of the harmonic divided by the fundamental system frequency allows the impedance of the inductive and capacitive reactance to be stated as
\[ X_{\text{Ln}} = n\omega L \]
\[ X_{\text{Cn}} = \frac{1}{n\omega C} \]

Since the imaginary part is zero at the resonance \( n=h \), then

\[ X_{\text{Lh}} = X_{\text{Ch}} \]  

Solving for \( h \) results in the design formula

\[ h^2 = \frac{X_{\text{C}}}{X_{\text{L}}} \]  

3.6 BASED ON POWER FACTOR IMPROVEMENT

3.6.1 Case Study 1

It may be recalled that the main reason for application of tuned capacitor bank is the need for improvement of PF and the reduction of harmonic. The tuned frequency for the series reactor and capacitor is selected below the fifth harmonic to allow for tolerance in the filter components and also to prevent a parallel resonance at any characteristic harmonics, 4.7\textsuperscript{th} harmonic was chosen for the filter tuned frequency. The correct size of reactor needed to
convert the 0.580 MVAr tuned capacitor bank into 4.7th harmonic filter is calculated using the above formula.

Using above equations the value for $X_C = 0.208 \ \Omega$ and for a 0.580 MVAr tuned capacitor bank applied to 11KV side result in a $X_L = 0.0095 \ \Omega$ for 4.7th harmonic filter. The filter components (L and C) of the passive shunt filter to suppress 5th harmonic component was calculated using a specially designed algorithm. Fig.3.3 shows the location of proposed filter bank. Flowchart and the process used to design filter are shown in Figs.3.4a and 3.4b. Steel Industry current THD and voltage THD measured on the 11KV system at PCC were in the range of 12-24% and 6-12%. The following Table 3.2 shows the comparison of different parameters at the main bus during periods of the heavy loading.

Table 3.2 Comparison of different parameters

<table>
<thead>
<tr>
<th>Details</th>
<th>By Direct Measurements</th>
<th>By Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>2.80</td>
<td>2.84</td>
</tr>
<tr>
<td>MVAr</td>
<td>1.76</td>
<td>1.7894</td>
</tr>
<tr>
<td>MVA</td>
<td>3.318</td>
<td>3.356</td>
</tr>
<tr>
<td>PF</td>
<td>0.845</td>
<td>0.846</td>
</tr>
</tbody>
</table>

Load compensation required = 0.580 MVAR
= 580 KVAR
CASE STUDY I

Fig 3.3 Single line diagram of Steel Plant with Filter
Fig. 3.4a Flowchart for the Design of Filter Components
Fig. 3.4 b Process used to Design Filter
The field measurements indicated that the 11KV system load was approximately 2.8MW with a 0.845 lagging power factor. In order to improve the 11KV system power factor to 0.92 lagging, addition of a tuned capacitor bank of 0.580 MVAr was necessary to provide the compensation. The filter details are given in Table 3.3.

3.6.2 Case study II

The average power factor of the plant is 0.74 and the desired power factor is 0.94. Fig.3.5 shows the location of proposed filter bank and the filter details are given in Table 3.4.

3.6.3 Case study III

The average power factor of the plant is 0.82 and the desired power factor is 0.95. Fig.3.6 shows the location of proposed filter bank and the filter details are given in Table 3.5.

3.6.4 Case study IV

The average power factor of the plant is 0.75 and the desired power factor is 0.94. Fig.3.7 shows the location of proposed filter bank and the filter details are given in Table 3.6.
Table 3.3 Design Calculation for fifth Harmonic Tuned Bank

<table>
<thead>
<tr>
<th>SI No</th>
<th>Parameters</th>
<th>Case Study I</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Power factor (initial)</td>
<td>0.845</td>
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<td>2.</td>
<td>Nominal Bus Voltage (kV)</td>
<td>11</td>
</tr>
<tr>
<td>3.</td>
<td>Power Reading (kW) at PCC Measurements/Software</td>
<td>2800</td>
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<tr>
<td>4.</td>
<td>Power factor required</td>
<td>0.92</td>
</tr>
<tr>
<td>5.</td>
<td>Filter Specification</td>
<td>5</td>
</tr>
<tr>
<td>6.</td>
<td>Supply Frequency</td>
<td>50</td>
</tr>
<tr>
<td>7.</td>
<td>Filter Tuning Harmonic</td>
<td>4.7</td>
</tr>
<tr>
<td>8.</td>
<td>Capacitor bank rating (KVAr)</td>
<td>579.21168</td>
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<tr>
<td>9.</td>
<td>Capacitive reactance $X_c$ (Ω)</td>
<td>0.20890</td>
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<td>10.</td>
<td>Inductive reactance $X_L$ (Ω)</td>
<td>0.00946</td>
</tr>
<tr>
<td>11.</td>
<td>Capacitance value (μFD)</td>
<td>15237.09131</td>
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<tr>
<td>12.</td>
<td>Inductance value (mH)</td>
<td>0.03010</td>
</tr>
<tr>
<td>13.</td>
<td>THD Value at PCC (Before filter was installed)</td>
<td>22</td>
</tr>
<tr>
<td>15.</td>
<td>THD Value at PCC (After filter installed)</td>
<td>7</td>
</tr>
</tbody>
</table>
CASE STUDY II

Short Circuit Capacity = 50 MVA

PCC,

2000 kVA 11/ 0.433 KV

Power Factor correction filter

VFD Load

Induction Furnace Load

Linear Load

Fig 3.5 Single Line Diagram of the Tool Manufacturing Plant with Filter
### Table 3.4 Design Calculation for seventh Harmonic Tuned Bank

<table>
<thead>
<tr>
<th>SI No</th>
<th>Parameters</th>
<th>Case Study II</th>
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</thead>
<tbody>
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<td>1.</td>
<td>Power factor (initial)</td>
<td>0.74</td>
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<tr>
<td>2.</td>
<td>Nominal Bus Voltage (kV)</td>
<td>0.433</td>
</tr>
<tr>
<td>3.</td>
<td>Power Reading (kW) at PCC Measurements/Software</td>
<td>976.8</td>
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<tr>
<td>4.</td>
<td>Power factor required</td>
<td>0.94</td>
</tr>
<tr>
<td>5.</td>
<td>Filter Specification</td>
<td>7</td>
</tr>
<tr>
<td>6.</td>
<td>Supply frequency</td>
<td>50</td>
</tr>
<tr>
<td>7.</td>
<td>Filter Tuning Harmonic</td>
<td>6.7</td>
</tr>
<tr>
<td>8.</td>
<td>Capacitor bank rating (KVAR)</td>
<td>533.31001</td>
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<td>9.</td>
<td>Capacitive reactance $X_c$ ($\Omega$)</td>
<td>0.00035</td>
</tr>
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<td>10.</td>
<td>Inductive reactance $X_L$ ($\Omega$)</td>
<td>0.00001</td>
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<td>11.</td>
<td>Capacitance value ($\mu$FD)</td>
<td>9054283.07875</td>
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<tr>
<td>12.</td>
<td>Inductance value (mH)</td>
<td>0.00002</td>
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<td>13.</td>
<td>THD Value at PCC (Before filter was installed)</td>
<td>14</td>
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<tr>
<td>15.</td>
<td>THD Value at PCC (After filter installed)</td>
<td>3.2</td>
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</tbody>
</table>
Fig. 3.6 Single Line Diagram of the Small Motor Manufacturing Industry with filter
Table 3.5 Design Calculation for fifth Harmonic Tuned Bank

<table>
<thead>
<tr>
<th>SI No</th>
<th>Parameters</th>
<th>Case Study III</th>
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<tbody>
<tr>
<td>1.</td>
<td>Power factor(initial)</td>
<td>0.82</td>
</tr>
<tr>
<td>2.</td>
<td>Nominal Bus Voltage (kV)</td>
<td>0.44</td>
</tr>
<tr>
<td>3.</td>
<td>Power Reading (kW) at PCC Measurements/ Software</td>
<td>32</td>
</tr>
<tr>
<td>4.</td>
<td>Power factor required</td>
<td>0.95</td>
</tr>
<tr>
<td>5.</td>
<td>Filter Specification</td>
<td>5</td>
</tr>
<tr>
<td>6.</td>
<td>Supply Frequency</td>
<td>50</td>
</tr>
<tr>
<td>7.</td>
<td>Filter Tuning Harmonic</td>
<td>4.7</td>
</tr>
<tr>
<td>8.</td>
<td>Capacitor bank rating (KVar)</td>
<td>11.81825</td>
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<tr>
<td>9.</td>
<td>Capacitive reactance $X_c$ (Ω)</td>
<td>0.01638</td>
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<td>10.</td>
<td>Inductive reactance $X_L$ (Ω)</td>
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<td>11.</td>
<td>Capacitance value (µFD)</td>
<td>194311.18542</td>
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<td>12.</td>
<td>Inductance value (mH)</td>
<td>0.00236</td>
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<td>13.</td>
<td>THD Value at PCC (Before filter was installed)</td>
<td>21</td>
</tr>
<tr>
<td>15.</td>
<td>THD Value at PCC (After filter installed)</td>
<td>4.6</td>
</tr>
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</table>
Fig. 3.7 The single line diagram of the Four Wheeler Brakes Manufacturing Industry with Filter
Table 3.6 Design calculation for fifth Harmonic Tuned Bank

<table>
<thead>
<tr>
<th>SI No</th>
<th>Parameters</th>
<th>Case Study IV</th>
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<tbody>
<tr>
<td>1.</td>
<td>Power factor(initial)</td>
<td>0.75</td>
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<tr>
<td>2.</td>
<td>Nominal Bus Voltage (kV)</td>
<td>0.433</td>
</tr>
<tr>
<td>3.</td>
<td>Power Reading (kW) at PCC Measurements/ Software</td>
<td>118</td>
</tr>
<tr>
<td>4.</td>
<td>Power factor required</td>
<td>0.94</td>
</tr>
<tr>
<td>5.</td>
<td>Filter Specification</td>
<td>5</td>
</tr>
<tr>
<td>6.</td>
<td>Supply Frequency</td>
<td>50</td>
</tr>
<tr>
<td>7.</td>
<td>Filter Tuning Harmonic</td>
<td>4.7</td>
</tr>
<tr>
<td>8.</td>
<td>Capacitor bank rating (KVAR)</td>
<td>61.23794</td>
</tr>
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<td>9.</td>
<td>Capacitive reactance $X_c$ ( $\Omega$ )</td>
<td>0.00306</td>
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<td>10.</td>
<td>Inductive reactance $X_L$ ( $\Omega$ )</td>
<td>0.00014</td>
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<td>11.</td>
<td>Capacitance value ( $\mu$FD)</td>
<td>1039668.50421</td>
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<td>12.</td>
<td>Inductance value (mH)</td>
<td>0.00044</td>
</tr>
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<td>13.</td>
<td>THD Value at PCC (Before filter was installed)</td>
<td>16</td>
</tr>
<tr>
<td>15.</td>
<td>THD Value at PCC (After filter installed)</td>
<td>6.8</td>
</tr>
</tbody>
</table>
3.7 DESIGN BASED ON POWER SYSTEM CHARACTERISTICS

The section discusses the application of revised IEEE Standard 519-1992 to tool manufacturing industry (case study II) where a combination of variable frequency drive (VFD) and induction furnace loads is used. The filter design is based on power system characteristics. To control the harmonics current injected into the power system, conditions are developed as a function of VFD and induction furnace characteristic, overall plant loading level and power system characteristics. Based on these parameters, filter design procedures are presented for controlling the harmonic currents.

The single line diagram of the industries studied is shown in Fig. 3.8. Harmonic spectrum for VFD and Induction furnace loads are given in Figs.3.9 and 3.10. These characteristics are used throughout this paper to evaluate harmonic control requirements. Short circuit ratio is 38.4 (i.e. 50 / 1.3) and referring to Table 3.1, harmonic current limit is 7 % and this will be used for analysis in the following Section.

3.7.1 Evaluation of harmonic limits without filter or capacitor

The simplest system configuration is assumed where there is no power factor correcting facility or no filter. Hence the harmonic current generated by VFD and induction furnace loads can be assumed to flow through the power system via step-down transformer. Therefore the VFD and Induction furnace plant loading can be derived using the current waveform provided previously. The VFD and Induction furnace plant loading should be expressed as a percentage of average maximum demand (1320 kVA in this case) to evaluate harmonic limits. Fig.3.11 gives the seventh harmonic current of the entire plant as a function of the plant VFD and Induction furnace loading for
CASE STUDY II

Short Circuit Capacity = 50 MVA

2000 kVA 11/0.433 KV

Figure 3.8 Single Line Diagram of the tool manufacturing plant with filter
VFD Current Harmonic Spectrum

Fig. 3.9 Type 1 waveform for 240 hp VFD with 3.2% choke

Induction Furnace Current Spectrum

Fig. 3.10 Type 2 waveform for Induction Furnace 750 kVA
Fig. 3.11 Seventh Harmonic Current Evaluation as a function of the total VFD and Induction Furnace loads.
two characteristic waveforms. Fig.3.11 refer to 25 % for VFD’s and 30 % for Induction furnace of the plant load. This is approximately true for lower order harmonics. However 30 % of the plant load may be for the VFD for higher order harmonics without exceeding the IEEE Standard 519-1992 limit.

### 3.7.2 Harmonic control with tuned capacitor bank

The addition of power factor correction capacitor causes a parallel resonance between the capacitor and system source inductance as shown Fig.3.12. Hence it is even difficult to meet IEEE Standard 519 harmonic current limits. It is understood that power factor correction capacitor should not be used without tuning reactor if VFD or Induction furnace loads constitute a significant percentage of plant load (i.e., exceeds more than 20 %).

The tuned frequency for the series reactor/capacitor is selected somewhere below the seventh harmonic (i.e., 6.7) to prevent parallel resonance at any characteristics harmonics. Fig.3.13 illustrates the effect of the tuned filter on the harmonic current at PCC and this shows significant reduction of the seventh harmonics. Fifth or ninth harmonic component from the VFD’S and Induction furnace will be the limiting component when evaluating the IEEE Standard 519 limits. The fifth and ninth harmonics are not the limiting case for type 1 current waveform or type 2 current waveform as shown in the Figs.3.14 and 3.15. Actually the VFD loading could even be somewhat higher than 30% of the plant load because some cancellation should be expected at these higher harmonic frequencies. The 11th harmonics and above form the limiting case for type 1 current waveform when tuned bank is added to control the lower order harmonics. Fig.3.16 shows that approximately 30 % of maximum plant load can be VFD’s in this case study. Filter configuration is shown in Fig.3.17 and Table 3.7 provides the rating of the filter component
Fig. 3.12 Parallel Resonance due to addition of Capacitor at the PCC

Fig. 3.13 Effect of Tuned Capacitor bank on the harmonic current at the PCC
Fig 3.14 Fifth harmonic current evaluation as a function of total VFD plant load and Induction Furnace with a tuned filter

Fig 3.15 Ninth harmonic current evaluation as a function of total VFD plant load and Induction Furnace with a tuned filter
Fig 3.16  Eleventh harmonic current evaluation as a function of total VFD plant load and Induction Furnace with a tuned filter

433 Voltage Bus

Fig. 3.17 Filter Configuration
for this case study (30% of the plant load is VFD plus 30% of the plant load is induction furnace).

Table 3.7 Design Calculation for 6.7\textsuperscript{th} Tuned Bank based on power system characteristics

<table>
<thead>
<tr>
<th>Design parameters of low voltage filter</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter specification</td>
<td>7\textsuperscript{th}</td>
</tr>
<tr>
<td>Capacitor bank rating</td>
<td>530 kVar</td>
</tr>
<tr>
<td>Nominal bus voltage</td>
<td>433 Volts</td>
</tr>
<tr>
<td>Capacitor bank current</td>
<td>697 amps</td>
</tr>
<tr>
<td>Filter tuning harmonic</td>
<td>6.7\textsuperscript{th}</td>
</tr>
<tr>
<td>Capacitor impedance Xc (wye equivalent)</td>
<td>0.00035 Ω</td>
</tr>
<tr>
<td>Reactor impedance</td>
<td>0.00001 Ω</td>
</tr>
<tr>
<td>Total harmonic load</td>
<td>792 KVA</td>
</tr>
<tr>
<td>Full load current</td>
<td>1039 amps</td>
</tr>
<tr>
<td>Load harmonic current</td>
<td>342 amps</td>
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<tr>
<td>Capacitance value</td>
<td>8998087.3375 μFD</td>
</tr>
<tr>
<td>Inductance Value</td>
<td>0.00003 mH</td>
</tr>
</tbody>
</table>

Table 3.8 gives important results of the analysis presented in this paper. The conclusion in Table 3.8 apply to primarily to VFD and Induction furnace and can be considered very useful for this types of drives involved.
Table 3.8 Thumb rule for maximum VFD and Induction furnace loading

<table>
<thead>
<tr>
<th>Condition</th>
<th>Type I VFD Load</th>
<th>Type II Induction Furnace Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No capacitor or no filter</td>
<td>25 %</td>
<td>30 %</td>
</tr>
<tr>
<td>433 volts tuned capacitor to 6.7th harmonics</td>
<td>30 %</td>
<td>30%</td>
</tr>
</tbody>
</table>

3.8 CONCLUSION

The harmonic filters are designed based on power factor improvement or power system characteristics as per IEEE Standard 519-1992. It is demonstrated that harmonics remain controlled within IEEE Standard 519-1992 limit. Identical results are obtained for both methods. The important results are presented for conditions when VFD and Induction furnace loads are used in the industry.