
Dr. Mrs. H. H. Kulkarni, Mrs. V. S. Jape, Dr. D. S. Bankar, Mr. R. V. Borkar

Abstract: Conventional power systems are designed to operate on sinusoidal power supply. Electric utilities strive to supply consumers with reliable & pure sinusoidal electric power that does not represent a damaging threat to their equipments. Due to globalization, use of non-linear devices have set the basis for paying considerable attention to the quality of electric power and seriously addressing the issue of current and voltage distortion - called Harmonic distortion. Now a days many devices are introduced to monitor and analyse the effects of harmonics on system and consumer devices. Paper presents the summary of results of survey of harmonics using advanced Power Quality analyser. The aim of survey is to identify the Power Quality levels which need the accomplishment of monitoring to find out the solutions to be implemented. Power Quality indices are analysed at Indian distribution network for various categories of non-linear consumers. This study leads to identify Power Quality level with respect to IEEE Standard 519-1992.

Index Terms: Harmonic distortion, Nonlinear load, Harmonic standard, Point of common coupling (PCC), Total Harmonic Distortion (THD), Distortion Index (DI).

1. INTRODUCTION

Power Quality is of ever growing concern to utilities and customers. The problem associated with high harmonic content in the power system not only results in poor quality of supply but also the operation of the system will get affected. Harmonic distortion is present in power distribution system since many years. The modern electronic devices and circuits are mostly non-linear. According to energy conservation act, demand of energy efficient devices is increased [1]. These energy efficient devices have two-fold problems with regard to harmonics. They not only produce harmonics but they are also very sensitive to the resulting harmonic distortion than the traditional power system devices. Presence of harmonics leads to reduction of equipment life, if the equipment is not properly designed. It is therefore important to measure, analyse and limit harmonics in power distribution network [4]. IEEE standard 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems (IEEE 519) [2], provides the basis for limiting harmonics. According to IEEE 519, the term Total Harmonic Distortion (THD) leads to Current THD and Voltage THD. Generally power system have low source impedance and well regulated supply but also the operation of the system will get affected. Harmonic distortion is present in power system 69KV and below is limited to 5.0% THD leads to Current THD and Voltage THD. Generally power system have low source impedance and well regulated voltage. So the resulting voltage distortion is very small even in the presence of current harmonics.

1.1 HARMONIC LIMITS

Each and every country has its own or adopted standards pertaining to power system networks. Voltage and Current Harmonic limits According to IEEE 519 are, harmonic voltage distortion in power system 69KV and below is limited to 5.0% Total Harmonic Distortion (THD) with each individual harmonic limited to 3%. The voltage and current harmonic limits are

- Dr. Mrs. H. H. Kulkarni*, PES’s Modern College of Engineering, Pune, India, hampiya.kulkarni@moderncoe.edu.in
- Mrs. V. S. Jape, Department of Electrical Engineering, Bharti Vidyapeeth Deemed University, Pune, India. Jape_swati@yahoo.co.in
- Dr. D. S. Bankar Department of Electrical Engineering, Bharti Vidyapeeth Deemed University, Pune, India. dbsbankar@bvcoep.edu.in
- Mr. R. V. Borkar, PES’s Modern College of Engineering, Pune, India,rupesh.borkar@moderncoe.edu.in

Current distortion limit is specified by ISC/IL ratio. It is the ratio of maximum short circuit current PCC to the maximum demand load current (fundamental frequency component) at PCC as shown at Table II. It should be noted that the main objective of IEEE standard 519-1992 is to limit the harmonic injection from individual consumer and to limit the overall harmonic distortion in the voltage and current supplied by the utility.

<table>
<thead>
<tr>
<th>Voltage Distortion Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus Voltage at PCC</td>
</tr>
<tr>
<td>69KV And below</td>
</tr>
<tr>
<td>69.001kv through 161kv</td>
</tr>
<tr>
<td>161.001kv and above</td>
</tr>
</tbody>
</table>

Note: High-voltage system can have upto 2.0%THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for user.

Table 2

IEEE standard 519-1992 harmonic current limits

<table>
<thead>
<tr>
<th>Current Distortion Limits for General Distribution Systems (130 V Through 69 000 V)</th>
</tr>
</thead>
</table>
| Maximum Harmonic Current Distortion in Percent of I_
| Individual Harmonic Order (Odd Harmonics)                                  |
| 110%                           | 135%                           | 160%                           | 185%                           | 210%                           | TDD |
| l_f /I_f                      | l_f /I_f                      | l_f /I_f                      | l_f /I_f                      | l_f /I_f                      |     |
| <20*                          | 4.0                            | 2.0                           | 1.5                           | 0.6                           | 0.3 |
| 20*                           | 2.0                            | 1.5                           | 1.0                           | 0.5                           | 0.3 |
| 30*                           | 1.5                            | 1.0                           | 0.5                           | 0.3                           | 0.3 |
| 50*                           | 1.0                            | 0.7                           | 0.5                           | 0.3                           | 0.3 |
| 100*                          | 0.5                            | 0.3                           | 0.3                           | 0.3                           | 0.3 |
| >100*                         | 0.3                            | 0.3                           | 0.3                           | 0.3                           | 0.3 |

Note: Harmonics are limited to 10% of the odd harmonic limits above.

Current distortions that result in a de-olt, e.g., half-wave converters, are not allowed.

*All power generation equipment is limited to these values of current distortion, regardless of actual I_f/I_f.

where

I_f = maximum short-circuit current at PCC.
I_d = maximum demand load current (fundamental frequency component) at PCC.
This standard emphasize the responsibility for limiting the harmonics on both customer and utility. Customer will be responsible for limiting the current harmonic injection and utility will be responsible for limiting the voltage harmonic distortion in the supply system.

2 COMPUTATIONAL PARAMETERS:
In last few years the performance evaluation of the system has undergone a remarkable change in respect of Power Quality. Power Quality monitoring and analysis was performed and results are calculated in the form of indices. Objective of derived Power Quality Indices is to qualify Distribution Network against the Distortion Index. In this regard, a new procedure is presented that evaluates the Distortion Index introduced by different types of non-linear loads connected to the power distribution network. It could be implemented in commercial network analyzers to carry out the analysis of the responsibility of each load on the total distortion of the power system. In presence of Harmonics, the voltage and current functions with respect to time can be expressed as

\[ v(t) = V_0 + \sqrt{2 \sum_{n=1}^{\infty} V_n \sin(n \omega t + \alpha_n) + V_H \sin(H \omega t + \alpha_H)} \]

(1)

\[ (t): \text{Instantaneous voltage. } V_0: \text{Average value} \]
\[ V_n: \text{RMS value of voltage harmonics} \]
\[ V_H: \text{Total Harmonic Distortion Voltage} \]
\[ \alpha_n: \text{Phase angle of voltage harmonic} \]

\[ i(t) = I_0 + \sqrt{2 \sum_{n=1}^{\infty} I_n \sin(n \omega t + \beta_n) + I_H \sin(H \omega t + \beta_H)} \]

(2)

Where \( v \)
\[ v(t): \text{Instantaneous voltage. } V_0: \text{Average value} \]
\[ V_n: \text{RMS value of voltage harmonics} \]
\[ V_H: \text{Total Harmonic Distortion Voltage} \]
\[ I_n: \text{RMS value of current harmonic.} \]
\[ I_H: \text{RMS value of current harmonic.} \]
\[ \alpha_n: \text{Phase angle of voltage harmonic} \]
\[ \beta_n: \text{Phase angle of current harmonic} \]
\[ \alpha_H: \text{Phase angle of voltage harmonic} \]
\[ \beta_H: \text{Phase angle of current harmonic} \]

Using (1) and (2) expressions, the fundamental component \( V_1 \) and \( I_1 \) from the harmonic component \( V_H \) and \( I_H \) gives.

\[ V = \sqrt{V_1^2 + V_H^2} \]

(3)

and

\[ I = \sqrt{I_1^2 + I_H^2} \]

(4)

Where: \( V_H \): RMS value of voltage harmonic.
\[ V_H = \sqrt{V_3^2 + V_5^2 + V_7^2 + \ldots} \]

(5)

\[ I_H = \sqrt{I_3^2 + I_5^2 + I_7^2 + \ldots} \]

(6)

\[ V_{THD}: \text{Total Harmonic Distortion Voltage} \]
\[ V_{THD} = \frac{V_H}{V_1} \]

(7)

Where, \( V_1 \): Fundamental component of voltage.

\[ I_{THD}: \text{Total harmonic Distortion Current} \]
\[ I_{THD} = \frac{I_H}{I_1} \]

(8)

Fundamental Apparent Power \( FAP = V_1 * I_1 \)
(9)

Current Distortion Power \( CDP = V_1 * I_H \)
(10)

Voltage Distortion Power \( VDP = V_H * I_1 \)
(11)

Harmonic Distortion Power \( HDP = V_H * I_H \)
(12)

Non-linear Apparent power \( NAP; \]
\[ NAP = \sqrt{CDP^2 + VDP^2 + HDP^2} \]
(13)

Total Apparent Power \( TAP = \sqrt{FAP^2 + NAP^2} \)
(14)

Distortion Index \( DI = (NAP/FAP)*100 \)
(15)

DI is improved Power Quality index as it directly relates to the distortion in power. As compared with the available THD as Power Quality parameter, it reflects either the voltage or the current distortion only. Hence it is important to include DI as major index which measures the levels of the harmonic pollution present to evaluate the Power Quality performance of the network. This index can also be used as “Quality factor” or “Penalty Factor” [3].

3 MEASUREMENT OF HARMONICS AND CALCULATION OF POWER QUALITY INDICES

Table 3 shows percentage total voltage harmonic distortion measured at different non-linear consumers. Table 4 depicts percentage total current harmonic distortion measured at different non-linear consumers. Power Quality indices are calculated for Consumer No. 4 and represented in Table No.5.

<table>
<thead>
<tr>
<th>Consumer no.</th>
<th>% ( V_{THD1} )</th>
<th>% ( V_{THD2} )</th>
<th>% ( V_{THD3} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AVG</td>
<td>AVG</td>
<td>AVG</td>
</tr>
<tr>
<td>2</td>
<td>2.56</td>
<td>2.42</td>
<td>2.48</td>
</tr>
<tr>
<td>3</td>
<td>0.243</td>
<td>0.044</td>
<td>0.12</td>
</tr>
<tr>
<td>4</td>
<td>0.165</td>
<td>0.045</td>
<td>0.0098</td>
</tr>
<tr>
<td>5</td>
<td>49.4</td>
<td>19.9</td>
<td>19.4</td>
</tr>
<tr>
<td>6</td>
<td>0.845</td>
<td>2.25</td>
<td>0.486</td>
</tr>
<tr>
<td>7</td>
<td>1.97</td>
<td>1.79</td>
<td>1.89</td>
</tr>
<tr>
<td>8</td>
<td>0.886</td>
<td>0.929</td>
<td>0.643</td>
</tr>
<tr>
<td>9</td>
<td>0.09</td>
<td>0.0714</td>
<td>0.946</td>
</tr>
</tbody>
</table>

Where \( i(t): \text{Instantaneous current.} \)
\[ i(t) = I_0 + \sqrt{2 \sum_{n=1}^{\infty} I_n \sin(n \omega t + \beta_n) + I_H \sin(H \omega t + \beta_H)} \]
(2)

<table>
<thead>
<tr>
<th>Consumer no.</th>
<th>% ( I_{THD1} )</th>
<th>% ( I_{THD2} )</th>
<th>% ( I_{THD3} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>AVG</td>
<td>AVG</td>
<td>AVG</td>
</tr>
<tr>
<td>2</td>
<td>20.9</td>
<td>18.7</td>
<td>20.1</td>
</tr>
<tr>
<td>3</td>
<td>42.7</td>
<td>45.9</td>
<td>47.6</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>6.89</td>
<td>5.7</td>
<td>6.32</td>
</tr>
<tr>
<td>6</td>
<td>20.1</td>
<td>18</td>
<td>19.3</td>
</tr>
<tr>
<td>7</td>
<td>6.74</td>
<td>4.7</td>
<td>5.7</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0.67</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>6.03</td>
<td>6.01</td>
<td>5.79</td>
</tr>
</tbody>
</table>

TABLE 5
4 DISCUSSION AND CONCLUSIONS:
This paper represents the Power Quality indices that gives contribution of each load on the total distortion of the power system. It includes distortion of voltage, current, power, total apparent power and also nonlinear apparent power. Therefore, this system gives a lot of information to users regarding the Power Quality. Much attention is now being paid to the Power Quality because of increasing use of non-linear loading. In the process it is essential to improve the power factor of the system by reactive power compensation and in addition to the harmonics present in the system are required to be almost nullified. The case studies presented here are the sample examples and it is necessary to improve the existing situation of Power Quality. The study leads to the following conclusions.
1. Electric utility must be able to evaluate, characterize and access the system performance to plan the system improvements for satisfying the Power Quality needs.
2. To track the performance of the system, It is important to consider Power Quality indices as one of the method of deciding the Power Quality.
3. The consumers who are polluting the Power Quality are required to be penalized logically through smart metering system [5].

In short it is necessary to test the validity of power system networks with particular reference to Indian context. Such a study makes it possible to rectify and correct the system.

ACKNOWLEDGEMENT
The authors wish to thank authorities of Bharti Vidyapeeth’s Deemed University College of Engineering, Pune for granting the permission to publish the work. Thanks to PES's Modern COE, Pune for providing experimental facilities and Maharashtra State Electricity Distribution Company Ltd. and Maharashtra State Electricity Transmission Company Ltd. for necessary help.

REFERENCEs