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PRACTICAL ANALYSIS AND MATHEMATICAL MODELING OF HARMONIC DISTORTIONS CAUSED BY ELECTRONIC LOADS

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ABSTRACT
Electronic loads draw non-sinusoidal current waveforms which produce undesired frequency contents known as harmonics in power distribution networks. Power Quality of distribution networks is severely affected due to generated harmonics during the operation of non-linear loads. In this paper, practical analysis of the factors influencing power quality has been presented. Experimental work has been carried out to obtain the innovative results in the form of Total Harmonic Distortion in Current (THDI), Total Harmonic Distortion in Voltage (THDV) and Power Factor (PF) caused by a single PC (Personal Computer) and then by increasing number of PC loads one by one. Finally mathematical expressions have been developed for the power quality parameters with different number of computers and tested practically. The results obtained using mathematical expressions have been compared with the practical results and exciting results have been concluded.

KEY WORDS
Electronic loads, Power quality, Power factor, Total Harmonic Distortion (THD)

1. Introduction

In this modern era, frequent use of digital appliances e.g. mobile phone, television, computer etc, is increasing continuously. These appliances have modernized the world's life style in many fields including communication and automatic control etc. The use of mentioned above equipment is inevitable now a days. Adversely, digital equipments are among those, which are the root cause for disturbances in distribution networks.

The percentage of Total Harmonic Distortion (%THD) can be defined in two different ways, as a percentage of the fundamental component (the IEEE definition of THD) or as a percentage of the rms (used by the Canadian Standards Association and the IEC) [1].

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} V^2{}_{h,rms}}}{V_{rms}} \times 100$$

$$V_{rms} = \sqrt{\sum_{h=1}^{\infty} V^2 h, rms}$$

The later standard is referred in this study. Where Vh,rms is the amplitude of the harmonic component of order h (i.e., the hth harmonic) and Vrms is the rms values of all the harmonics) [1].

In literature various approaches to mitigate these problems have been presented. Reference [2] presents a novel approach for automated power quality improvement and neutral conductor current reduction. An analysis and mitigation of voltage flickering in Power systems has been addressed in reference [3].

Another approach has been discussed using decomposition of power system harmonics by wavelet technique [4] which analyses the harmonic distortions both in time domain as well as in frequency domain. Harmonics mitigation using adaptive filtering technique has been presented in reference [5]. Reference [6] gives a way of line harmonics reduction using Fuzzy logic controller based Three-Phase Shunt active filter.

The effects of harmonic components on different equipment have been studied in [7, 8, 9]. Practical recording and discussion on power quality measures is presented in [10, 11]. Difference in this recording of practical results in reference [10, 11] and the work presented in this paper is that, they have recorded their parameters at distribution grid level on mixed load while in this paper; isolated electronic load is connected in increasing order in a proper sequence to develop mathematical models. References [12, 13] investigated the net harmonic currents, harmonics attenuation and diversity.

Section 2 explains the methodology and course adopted during the conducted experiments. Section 3 gives the practical details and apparatus used along with the specifications of the electrical equipment used during this work. Section 4 summarizes the experimental results and observations. Section 5 narrates the results obtained and deductions drawn from those observations. In section 6 mathematical and practical results have been compared. Section 7 presents conclusions drawn from this research work. Last Section gives all the references used throughout this research work.

2. Methodology

In this work various computers were connected to the main of the power supply one by one and effect of each computer on the voltage and current waveform of the main was recorded.
Figure 1 explains the situation which is a crude diagram of the hardware arrangement and apparatus used during the experimental work.

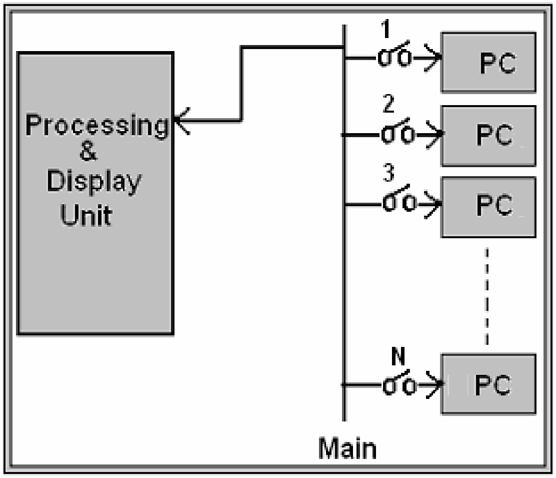

Figure 1: Schematic diagram

As is evident from Figure 1, inputs for various computers under test one by one are drawn from AC main. Then waveforms of various variables like current, voltage, power factor, Total Harmonic Distortion in current and Total Harmonic Distortion in voltage have been observed and recorded. Then this data has been used to make observations about the changes and effects of electronic loads.
The recorded data has been analyzed for some important conclusions about the nature of electronic loads. Even if configuration of electronic load attached to the system changes, still predictions about the behavior of these loads can be made. Keeping in view as EPRI (Electric Power Research Institute) reported that in near future 50% of the over all load connected to the system will be electronic in nature. So it will be much easier to apply preventive and corrective measures for improvement in performance of the distribution networks with special regards to power quality.

3. Testing Equipment

Following equipment have been used for the research work.

i) Power quality analyzer was used to record the voltage & current waveforms, THD and Power factor.
ii) Personal Computer(PC) details are as under:
Pentium (R) 4 CPU 2.40 GHz
ATX Power supply 220 t0 230 Volts
Monitor 15 inch (100- 240V, 50/60Hz, 0.8-1.5A)

4. Experimental Results

Various PCs were connected to the AC main and then wave-forms of both current and voltage at main have been captured and recorded in real time for observations. Table 1 describes the results taken for Total Harmonic Distortion in current (THDI), Total Harmonic Distortion in voltage and power factor corresponding to different number of PCs connected to the main.

PCs	THDI (%)	THDV (%)	Power factor
01	79.3	2.7	0.60
02	78.2	2.9	0.61
03	76.0	3.0	0.63
04	74.6	3.1	0.64
05	74.2	3.2	0.65
06	73.7	3.3	0.66
07	72.3	3.4	0.67
08	71.5	3.5	0.68
09	70.7	3.6	0.68
10	70.1	3.7	0.69
11	69.7	3.9	0.69
12	69.2	4.1	0.70
13	68.6	4.4	0.70
14	67.9	4.7	0.71
15	67.1	4.9	0.71
16	66.2	5.2	0.72
17	65.4	5.5	0.72
18	64.7	5.7	0.73
19	64.0	5.9	0.73
20	63.5	6.1	0.74
21	62.8	6.3	0.74
22	62.1	6.5	0.75
23	61.4	6.7	0.75

Table 1: Practically recorded results

The recorded waveform of current and voltage in time domain on a single graph for 11 PCs connected to the main is shown below in Figure 2.

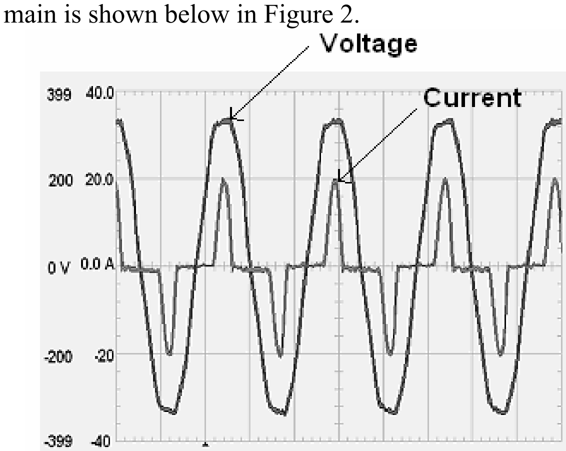

Figure 2: Distorted signal (11 PCs)

The voltage waveform is distorted from the points at which current spikes are drawn by the nonlinear load.

Current waveform in frequency domain is displayed in Figure 3.

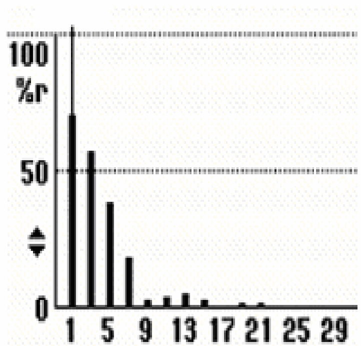

Figure 3: FFT of current waveform (for 11 PCs)

Voltage waveform in frequency domain is displayed in Figure 4.

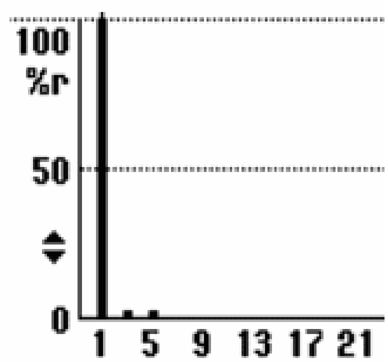

Figure 4: FFT of voltage waveform (for 11 PCs)

Distorted waveforms of current and voltage in time domain and then in frequency domain for 23 PCs are shown in the following figures.

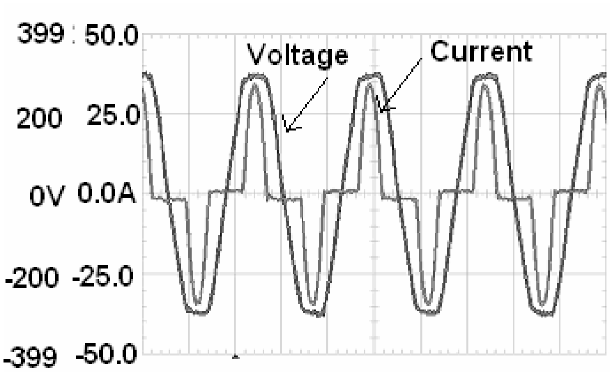

Figure 5: Distorted signal (23 PCs)

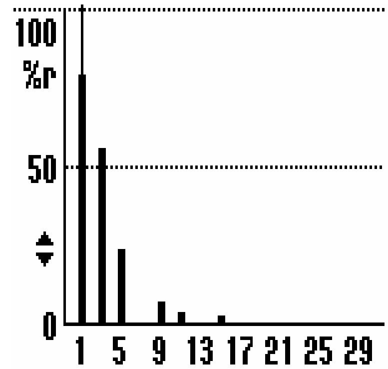

Figure 6: FFT of current waveform (for 23 PCs)

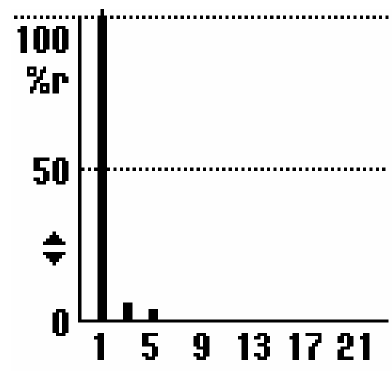

Figure 7: FFT of voltage waveform (for 23 PCs)

4.1 Graphical Representation of Results

Graph has been plotted and shown between THDV and increasing the number of PCs in figure. 8.

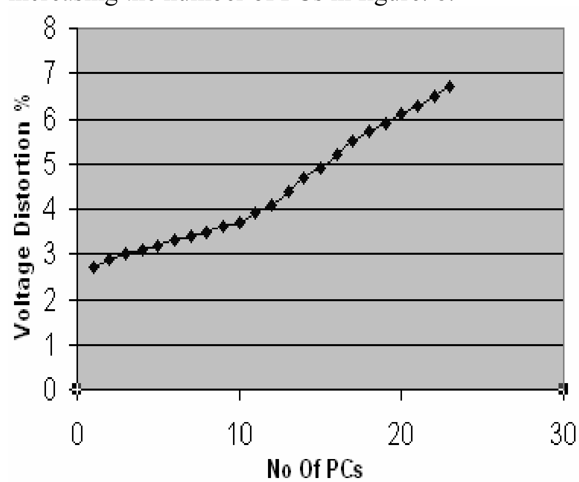

Figure 8: Percentage voltage distortions

Graph between THDI and increasing the number of PCs is shown in Figure. 9.

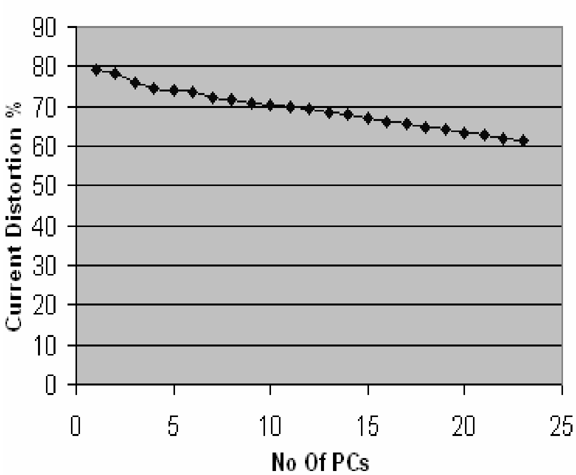

Figure 9: Percentage current distortions

Figure 10 gives relation between power factor and total number of PCs connected.

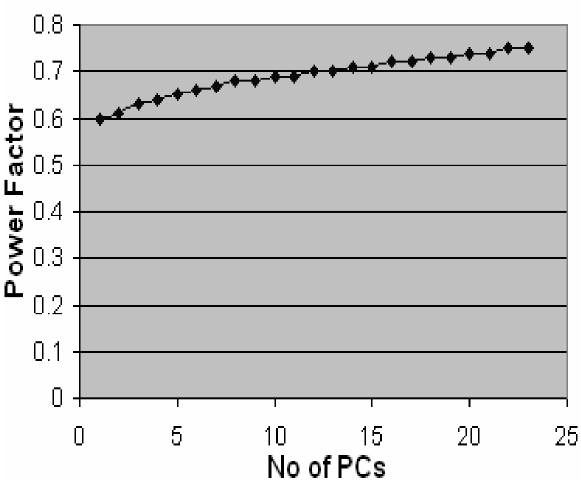

Figure 10: Power factor

5. Mathematical Modeling and Derivations

Based upon the tabulated observations of real time data, its mathematical expressions have been developed in this section.

It is evident from the experimental results that the voltage distortions tend to increase with the increasing number of PCs (Figure 8) whereas current distortions are decreasing with the increasing number of PCs (Figure 9). Similarly for power factor, it tends to improve with the increasing number of PCs (Figure 10).

In most cases, the quality of voltage is being addressed as the quality of power; because power supply system can control only the quality of voltage. It has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintain the supply voltage within certain limits. So it is the voltage with which we are ultimately concerned. We must also address the current due to which these voltage disturbances are produced. [14]

The mathematical models developed from the presented results have been tested practically for their evaluation as follows

$V_t =$ Voltage Distortions

$I_t =$ Current Distortions

$N_{pcs} =$ Number of Personal Computers

$PF =$ Power Factor

From the experimental results for total distortions following observations may be inferred:

(i) There is approximately a linear relationship between number of PCs and total voltage distortions with a positive slope as shown in Figure 8.

(ii) There is an approximate linear relationship between number of PCs and total current distortions with a negative slope as shown in Figure 9.

(iii) There is an approximate linear relationship between number of PCs and Power Factor with a positive slope as given in Figure 10.

As the graphs are almost linear; using two point form of the equation of line; relations between all the 4 parameters have been developed as follows:

$$\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1}$$

For total voltage distortions the equation may be re-written as

$$\frac{v_t - v_{t1}}{v_{t2} - v_{t1}} = \frac{N_{pcs} - N_{pcs1}}{N_{pcs2} - N_{pcs1}}$$

$\Rightarrow$

$$V_t = 0.1818 \times N_{pcs} + 2.518 \qquad (1)$$

Similarly for total current distortions and power factor mathematical expressions have been developed which are given below

$$I_t = 80.11 - 0.81 \times N_{pcs} \qquad (2)$$

$$PF = 6.818 \times 10^{-3} \times N_{pcs} + 0.5931 \qquad (3)$$

6. Comparison of calculated and measured results

Using the above developed equations, values for an increased number of PCs were calculated and then compared with actual values obtained practically and were found to be in close match with each other. This proves the validity of the equations developed and their applicability in real life applications

Randomly Picked Number of PCs	Practical Voltage Distortion / Formulated Voltage Distortion	Practical Current Distortion / Formulated Current Distortion	Practical PF / Formulated PF	%age Error Voltage	%age Error Current	%age Error PF
15 PCs	4.9% / 5.227%	67.1% / 67.96%	0.71 / 0.6953	6%	1.28%	2.07%
20 PCs	6.1% / 6.154 %	63.5% / 63.91%	0.74 / 0.7167	0.8%	0.62%	3.1%

Table 2: Comparison of real/calculated values

The comparison of the values has been summarized in Table 2. From this comparison it may be easily concluded that mathematical model developed and the actual values obtained match each other significantly resulting in novel vision for calculation of factors affecting power quality in distribution networks.

Same model may be used for evaluation of power quality of any proposed electrical distribution network and for suggesting necessary remedial measures.

7. Conclusion

It has been observed during this research work that there is approximately a linear relationship in current distortions and voltage distortions with the increasing number of PCs. So a mathematical model may be developed which may afterwards be used for the evaluation of expected voltage distortion in any power distribution network.

Once a mathematical model has been developed for the distribution network under observation, and using that mathematical model; future response of any proposed power distribution network can be predicted, remedial steps for any network may then be suggested and subsequently applied for better performance and improved power quality.

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