Background Voltage Distortion and Percentage of Nonlinear Load Impacts on the Harmonics Produced by a Group of Personal Computers

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***Abstract*—The penetration of nonlinear loads on power systems increases distortion levels and can cause severe problems to power systems. Many factors affect the degree of generated harmonics including the background voltage distortion and percentage of nonlinear load to the total load. Hence, the purpose of this paper is to investigate and accurately quantify the effects of these two factors on the harmonics produced by a group of Personal Computers (PCs). Experimental measurements and computer simulations are performed to confirm the observations.**

Index Terms— Distortion; Harmonics; Power Quality; Personal Computer; THD.

I. INTRODUCTION

Residential customer's input voltages are increasingly becoming more distorted due to the recent proliferation of nonlinear loads within power systems such as Personal Computers (PCs). It has been estimated that by 2012, 60% of the loads on power systems will be nonlinear [1]. The penetration of these loads increases the harmonic level in power system networks and can cause severe problems such as an increase in voltage distortion, decrease in Power Factor (PF), system resonance, equipment failure, impact energy metering, thermal effects on rotating machines, increase system losses, malfunction of electronic devices and decrease in the overall system efficiency [2-7].

PCs are among the most commonly used nonlinear loads in residential and commercial buildings nowadays. Although their rated powers are quite small to individually pollute the quality of power systems, their accumulated effects can be significant especially if they are connected to weak systems.

A number of studies have been conducted to investigate the factors that can affect the harmonics produced by nonlinear loads. In [8-14], attenuation, which refers to the interaction of voltage and current distortions due to shared system impedance, and diversity, which refers to the partial cancellation of harmonic currents due to phase angle diversity, are discussed. The effects of mixing single and three phase nonlinear loads on harmonic cancellation are also quantified in [15]. Harmonic cancellation due to different single-phase nonlinear loads is illustrated in [16]. It is also proven by simulation in [8, 14, 17] that background voltage distortion affects current harmonics. In [18], voltage, impedance and frequency variations effects on the harmonics generated from a single PC are discussed. Attempts to quantify the effect of linear loads on the generated harmonics are given in [19].

However, all previously mentioned experimental studies, except [18, 19], have not employed purely sinusoidal power supplies. Hence, harmonics quantification due to a particular factor is not fully assessed. One of the key objectives of this research study is to evaluate the effects of the background voltage distortion and percentage of nonlinear load to the total load individually and precisely. This is achieved by controlling the input voltage magnitude, frequency, source impedance and background voltage distortion using a programmable AC source Chroma^{TM} 61511 [20]. The Chroma helps in isolating the test rig and filtering out harmonics and fluctuations from the mains. Also, a high accuracy KinetiQ PPA1530 Power Analyzer was used to monitor the input voltage and current of the PCs [21]. This research study considers a group of 20 PCs.

The effects of the background voltage distortion on the harmonics generated by the PCs are assessed by experimental measurements and simulation using Matlab Simulink [22]. Both measurements and simulations give close results to each other and hence to be succinct only measurement results are presented here unless otherwise stated.

The paper is organized as follows. Section II introduces the most commonly used indices for harmonics quantification. Section III discusses the effects of background voltage distortion on the produced harmonics. Then, the impact of the nonlinear load percentage to the total load is introduced in section IV. Finally, section V presents the summary and conclusions.

II. HARMONIC INDICIES CALCULATIONS

The presence of harmonics makes waveforms to be nonsinusoidals. The most commonly used indices to quantify voltage and current distortions are Voltage and Current Total Harmonic Distortion that can be calculated as follows.

$$THD_v = \frac{V_H}{V_1} = \sqrt{\left(\frac{V}{V_1}\right)^2 - 1} \qquad (1)$$

$$THD_I = \frac{I_H}{I_1} = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1} \qquad (2)$$

where:

V, V_1 and V_H represent the total, fundamental and harmonic voltages.

I, I_1 and I_H denote the total, fundamental and harmonic currents.

III. BACKGROUND VOLTAGE DISTORTION

Although many papers have discussed the effects of background voltage distortion and flattened tops voltage sources on THD_i [12, 17, 23], no experimental measurements have been done to draw the relation between the background voltage distortion with THD_i and individual harmonic currents under different distortion conditions for a group of nonlinear loads. According to [3], the IEEE recommended voltage distortion in distribution systems should not exceed 5%. Hence, the background voltage distortion varies from 0% (sinusoidal waveform) to 5%. Figs. 1 and 2 show that increasing the voltage distortion from 0% to 5%, increases THD_v of 20 PCs from 1.3 to 5.5% while THD_i decreases by about 29%. Also, increasing the connected loads to 20 PCs at 5% voltage distortion increases THD_v and decreases THD_i by approximately 10.5% and 5.8%, respectively.

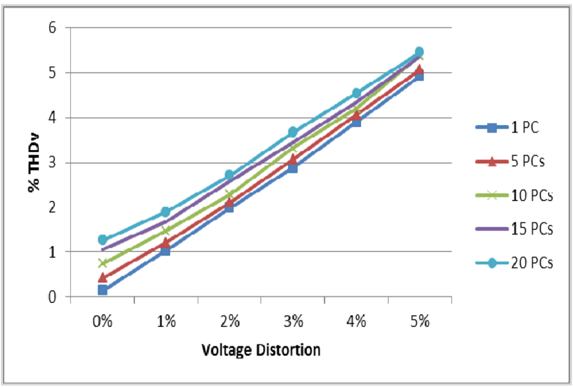

Figure 1. THD_v vs. background voltage distortion

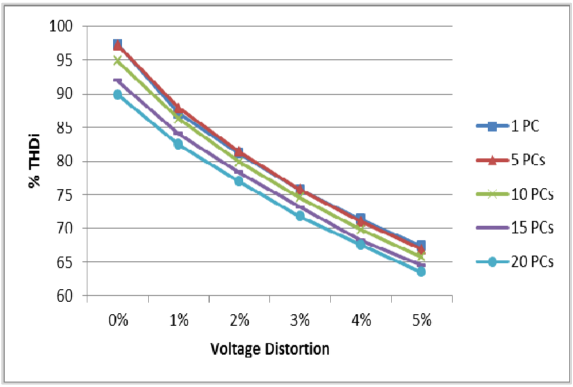

Figure 2. THD_i vs. background voltage distortion

For predicting individual harmonics behaviors to perform a resonance study or calculating harmonic losses, assessing the effects of background voltage distortion on individual harmonics is required. Figs. 3 and 4 illustrate that increasing voltage distortion to 5% increases the 3rd harmonic voltage magnitude about five times, while decreases the 3rd harmonic current magnitude by 28% when a group of 20 PCs is considered.

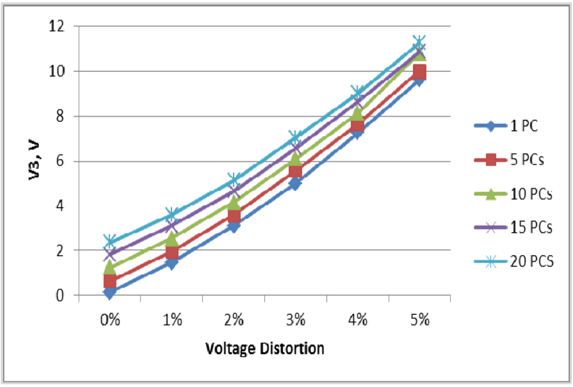

Figure 3. 3rd harmonic voltage vs. background voltage distortion

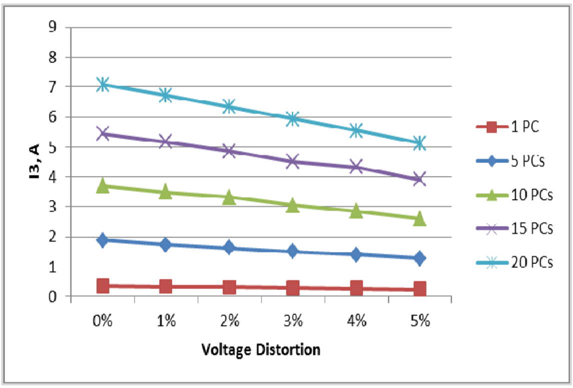

Figure 4. 3rd harmonic current vs. background voltage distortion

The same analysis is repeated again considering the 5th harmonic that follows the same behavior as the 3rd harmonic as shown in Figs. 5 and 6.

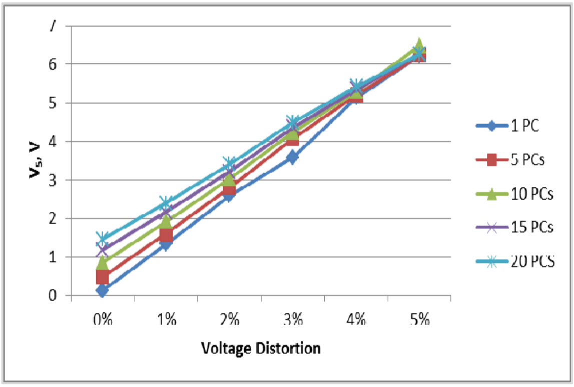

Figure 5. 5th harmonic voltage vs. background voltage distortion

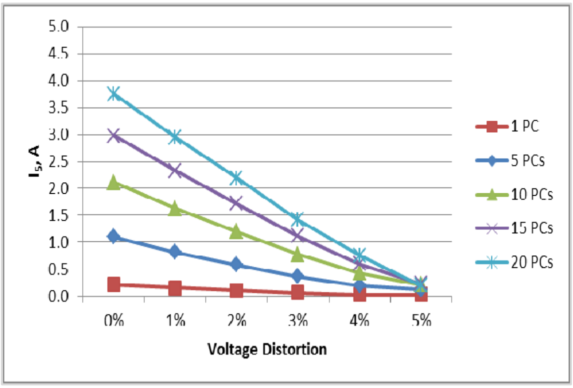

Figure 6. 5th harmonic current vs. background voltage distortion

The analysis of the 7th harmonic illustrated in Figs. 7 and 8 show that the 7th order voltage harmonic increases until the background voltage distortion becomes 4% after which it decreases. Regarding the 7th harmonic currents, they decrease when the background voltage distortion is 1% and increase 5 times when the background voltage distortion increases from 1% to 5%.

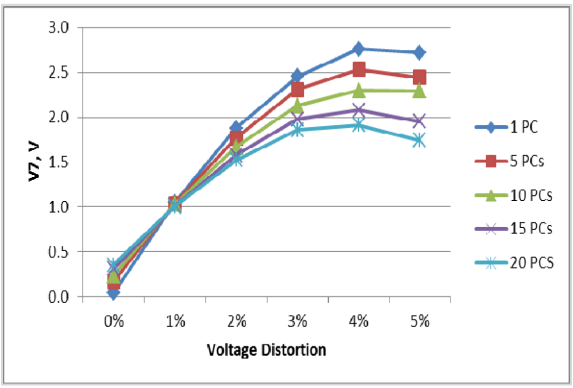

Figure 7. 7th order harmonic voltage vs. background voltage distortion

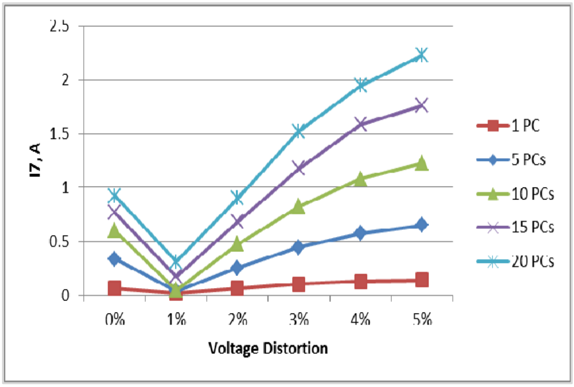

Figure 8. 7th order harmonic current vs. background voltage distortion

Another set of measurements were carried out to evaluate the effects of varying the 3rd harmonic background voltage percentage (% of V_3/V_1) from 17.75% to 24.50% on the harmonics generated by a single PC. Fig. 9 shows that THD_v, THD_i and $\%I_5$ increase with increasing the 3rd harmonic voltage distortion while $\%I_3$ and $\%I_7$ decrease then increase. This proves that under certain conditions, some sort of current harmonics amplification can occur [14, 17]. However, if the results presented in Fig. 9 are compared with those of Fig. 2, it can be noticed that when $\%V_3$ is zero (corresponds to sinusoidal wave), THD_i is about 97%, while when $\%V_3$ is 17.75%, THD_i is 62%.

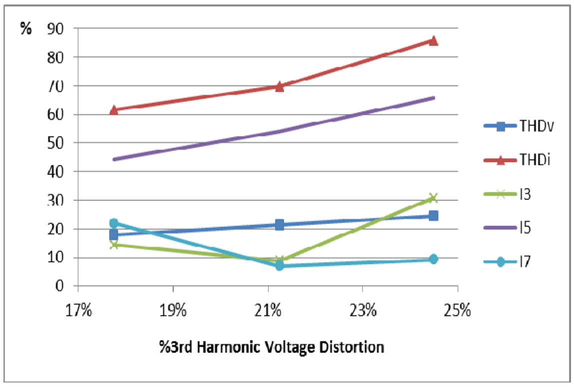

Figure 9. PC Harmonic indices vs. %3rd background voltage distortion

When the effects of the background voltage distortion on THD_v, THD_i, 3rd and 5th voltage and current harmonics are simulated, they follow the same trend as in Figs. 1-6 with slight differences in the percentages and magnitudes. However, the 7th harmonic voltage and current behave differently as shown in Figs. 10 and 11.

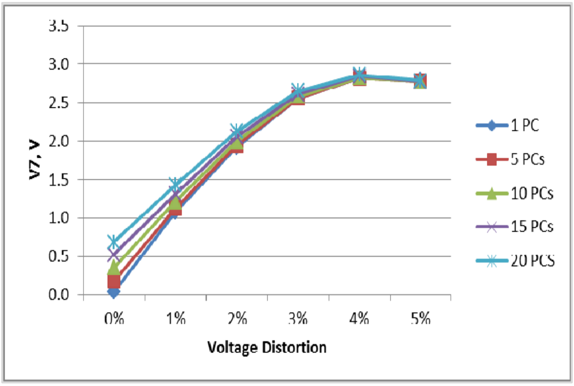

Figure 10. 7th harmonic voltage vs. background voltage distortion (simulation)

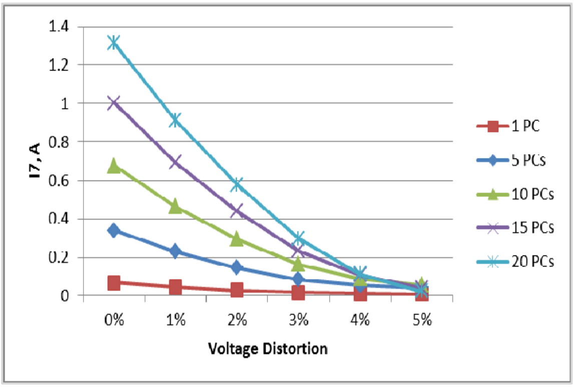

Figure 11. 7th harmonic current vs. background voltage distortion (simlation)

These different behaviors may be due to the fact that the 7th harmonic filter design used in the PC modeling is not exactly the same as that of the actual PCs. Because, when different 7th harmonic filter designs are used, closer results to measurements are obtained, but at the expense of worsening other indices like THD_v, THD_i and other individual harmonics. It should be noted that the full and constant load power models presented in [24, 25] are used in this paper to perform the simulations.

IV. Percentage of Nonlinear Load to the Total Load

One of the most important factors that affect THD_i and other individual current harmonic indices is the percentage of nonlinear load to the total load. As more linear loads are connected to the same supply, harmonic indices decrease. However, the distortion current ($\sqrt{\sum I_n^2}$) is constant. Fig. 12 illustrates the percentage decrease in THD_i as the linear load increases.

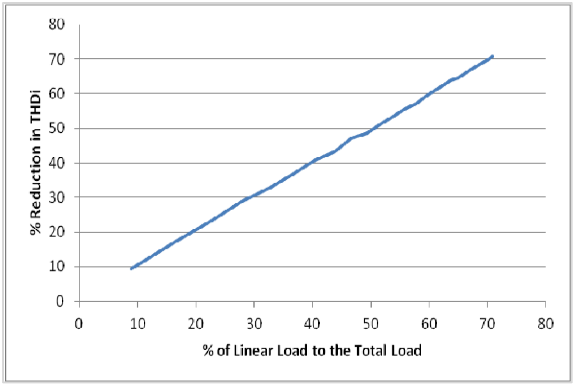

Figure 12. Reduction of THD_i as a function of linear load percentage

This can also be proven by referring to the following equation.

$$\Delta THD_i\,\% = \left[\frac{\dfrac{\sqrt{\sum I_n^2}}{I_{1PC}} - \dfrac{\sqrt{\sum I_n^2}}{I_{1Total}}}{\dfrac{\sqrt{\sum I_n^2}}{I_{1PC}}}\right] \times 100 = \left[1 - \frac{I_{1PC}}{I_{1Total}}\right] \times 100 \quad (3)$$

where:

I_{1PC} is the fundamental current drawn by the PC only.

I_{1Total} is the fundamental current drawn by the PC and linear load.

Fig. 13 illustrates that with the same nonlinear load (PC), $\%THD_i$ decreases rapidly from more than 96% (corresponds to when the PC load is the only load) to below 30% (corresponds to about a 30% the PC load to the total load). $\%I_3$, $\%I_5$ and $\%I_7$ also decline, although their absolute values are almost constant. This means that these distortion indices could sometimes mislead and magnitudes in amperes or voltages should also be monitored and analyzed.

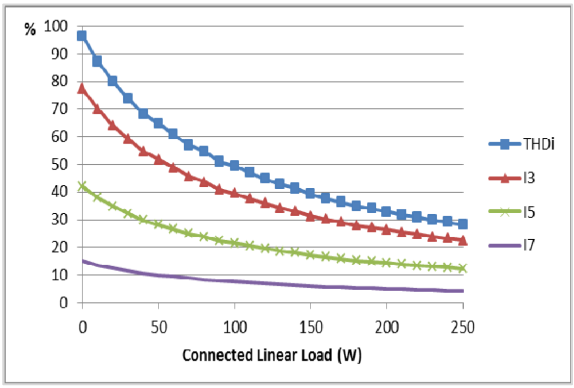

Figure 13. $\%THD_i$ and %Is with the increasing of the connected linear load.

$\%I_3$, $\%I_5$ and $\%I_7$ are the percentages of the 3rd, 5th and 7th harmonic currents to the fundamental current. Recall from equation (2), as more linear loads are connected to the same supply, the fundamental current increases and THD_i decreases. $\%I_3$, $\%I_5$ and $\%I_7$ also decrease with increasing I_1.

V. CONCLUSION

Power systems harmonics are continuously varying due to many factors including the variation in the background voltage distortion and percentage of nonlinear loads connected to the same supply. Background voltage distortion affects THD_i, THD_v and individual harmonics significantly as THD_v increases about 5 times while THD_i can be reduced by about one third when the background voltage distortion varies within IEEE recommended limits. Individual harmonics tend to behave differently with increasing background voltage distortion as 3rd and 5th harmonic voltages increase while harmonic currents decrease, whereas the 7th harmonic voltage initially increases then decreases while the 7th harmonic current decreases then increases. Percentage of nonlinear load to the total loads does not affect the harmonics' magnitudes, but reduces the harmonic indices sharply if a bulky linear load is connected to the same source supplying the nonlinear loads.

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