Factors Affecting the Harmonics Generated by a Cluster of Personal Computers

Muhyaddin J. H. Rawa, David W. P. Thomas, Mark Sumner
Electrical Systems and Optics Research Division
The University of Nottingham
Nottingham, UK
mrawa@kau.edu.sa, dave.thomas@nottingham.ac.uk, mark.sumner@nottingham.ac.uk

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 attenuation, diversity, system voltage, source impedance and frequency. Hence, the purpose of this paper is to investigate and accurately quantify the effects of these factors on the harmonics produced by a group of Personal Computers (PCs). Experimental measurements and computer simulations are performed to confirm the observations.**

Keywords- Distortion, harmonics, Power Quality, Personal Computer; THD.

I. INTRODUCTION

Recently, residential customer's input voltages are increasingly becoming more distorted due to the increase use 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 loads [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, a decrease in Power Factor (PF), impact energy metering, system resonance, thermal effects on rotating machines, equipment failure, increase system losses, malfunction of electronic devices and decrease the overall system efficiency [2-5].

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 [6-10], 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 non-linear loads on harmonic cancellation are also quantified in [11]. Harmonic cancellation due to different single-phase nonlinear loads is illustrated in [12]. It is also proven by simulation in [13] that background voltage distortion affects current harmonics. In [14], voltage, impedance and frequency variations effects on the harmonics generated from a single PC are discussed.

However, all previously mentioned experimental studies, except [14], 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 different factors 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 [15]. 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 device under test [16]. This paper considers the effects of system voltage and frequency variations on a group of PCs. Furthermore, not only impedance magnitude, but also impedance X/R ratio variation is considered. This paper also takes into account the effects of attenuation and diversity effects on the harmonics generated by a group of PCs. Finally, experimental measurements of various power quality and harmonic quantification indices of a laptop supplied by different power systems are introduced.

In this paper, various power quantities are considered including, the Root-Mean-Square (RMS) values of the input voltage and current, Power Factor (PF), active (P), nonactive (N) and apparent power (S). These quantities are calculated according to the IEEE Std 1459 [17]. Voltage and Current Total Harmonic Distortion indices (THD_v and THD_i) as well as Individual Current Harmonic Distortion (IHD) up to the 11th order harmonic are also considered.

The paper is organized as follows: Section II discusses the various factors that may affect the produced harmonics.

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Then, results for a laptop fed by different power system conditions are introduced in section III. Finally, Section IV presents the summary and conclusions.

II. FACTORS AFFECTING PRODUCED HARMONICS

If the background distortion of a 240V supply is monitored, it can be seen that THD_v is varying all the time. Similarly, if the secondary currents of a distribution transformer supplying different nonlinear loads are measured, THD_i is always changing depending on the loads that are being switched on/off, the level of the background distortion or even the amount of linear loads fed through the same transformer.

The characteristic of a nonlinear load can change even if it is fed from a constant supply. Fig. 1 illustrates how THD_i changes from the time of turning on the PC to steady state. Similarly, Fig. 2 shows a THD_i from a continuous monitoring of a 240V system under different load and system conditions in which THD_i varies from about 95% to less than 5% within 15 minutes.

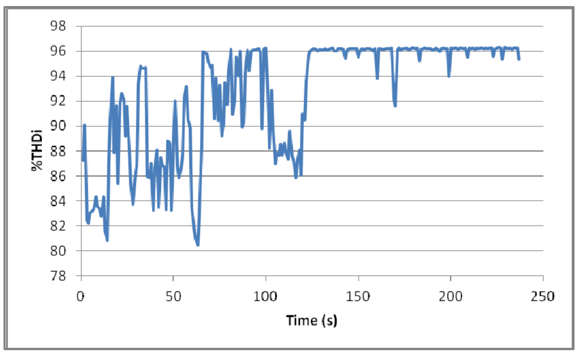

Figure 1. PC THD_i variation during start up.

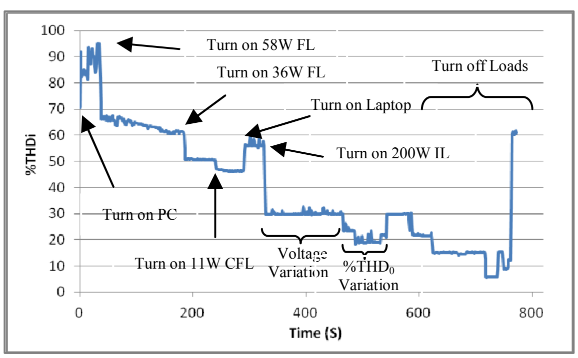

Figure 2. THD_i variation caused by different system and load conditions (Compact Fluorescent Lamp (CFL), Fluorescent Lamp (FL), Incandescent Lamp (IL), PC and Laptop).

It should be noted that the different factors considered in this research are examined through simulation using Matlab Simulink [18] and experimental measurements. Both simulations and measurements give close results to each other and hence to be succinct only measurement results are presented here.

A. *Voltage Variation*

Almost all residential customers are subjected to variations in the system voltage such as overvoltages and undervoltages, for many reasons. In order to assess the effects of voltage variation on the harmonics generated from a group of PCs, the input voltage is set to be ±5% on a 240V supply. It can be seen from Fig. 3 that a group of ten or more PCs voltage variation has a minor effect on THD_v. However, Fig. 4 shows that increasing the system voltage increases current distortion. This is because the output power is controlled; hence, the higher the input voltage, the lower the input current and the higher current distortion. Although all curves in Fig. 4 have the same slope, and therefore same percentage effect due to voltage change, THD_i of 20 PCs is about 7% lower than that of a single PC.

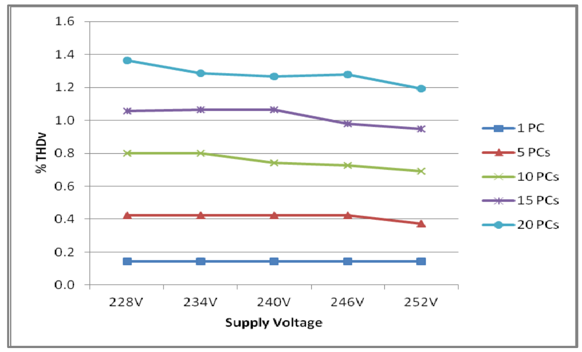

Figure 3. PCs THD_v vs. voltage variation

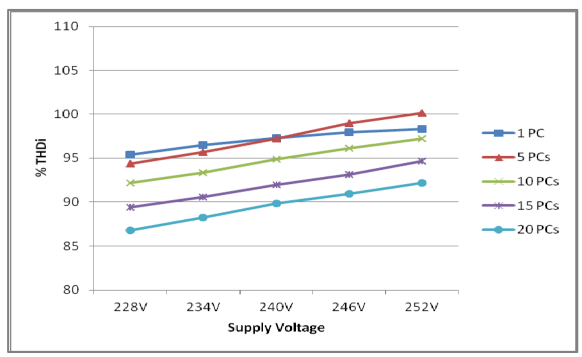

Figure 4. PCs THD_i vs. voltage variation

B. *Impedance magnitude and X/R ratio Variations*

Source impedance magnitude and X/R ratio are different for different customers depending on their distance from utility transformers and distribution cabinets and system loading. In [19], it is shown that source impedance within the allowed limits has small effects on the harmonics generated from a single PC and current distortion tends to decrease with increasing source impedance. In order to generalize the conclusion, the same experiment was repeated again for a group of up to 20 PCs supplied through a wider range of system impedance magnitudes. Figs. 5 and

6 show that although THD_v and THD_i of a single PC are almost fixed. However, when a group of 20 PCs are fed from the same supply THD_i decreases by more than 15% and THD_v is about four times greater for maximum system impedance.

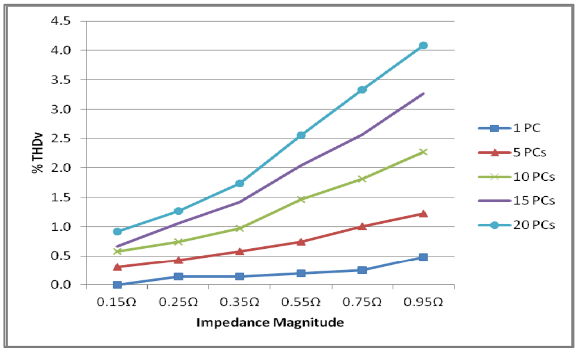

Figure 5. THD_v vs. impedance magnitude variation

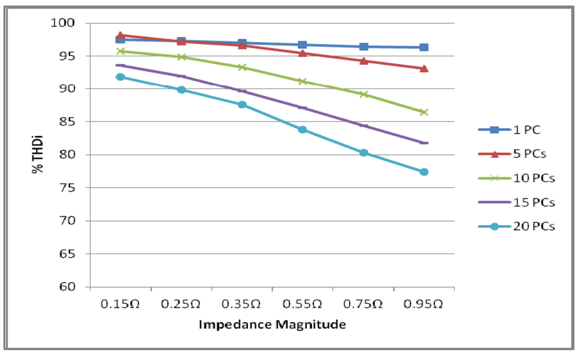

Figure 6. THD_i vs. impedance magnitude variation

Depending on their location within a building and since the internal connections of any building are mainly resistive, source impedance X/R ratio could be different for different sockets. Hence, another set of measurements was carried out which considers variation in X/R ratio rather than impedance magnitudes. Figs. 7 and 8 show that THD_i values are almost the same despite X/R ratio variation while THD_v increases with increasing the X/R ratio especially when a group of 10 or more PCs is considered. In the presence of harmonics, higher X/R ratio gives greater impedance values for increasing harmonic frequencies.

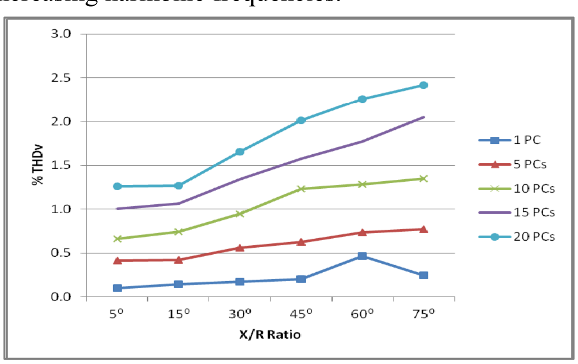

Figure 7. THD_v vs. X/R ratio variation (arc tan X/R)

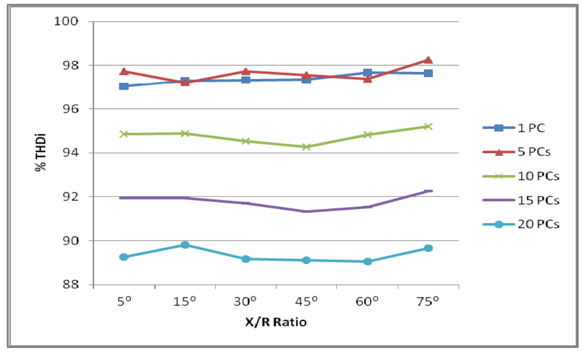

Figure 8. THD_i vs. X/R ratio variation (arc tan X/R)

C. Frequency Variation

Faults on bulk transmission systems and disconnection of a large block of loads may cause system frequency change [6]. Both simulation and measurements prove the study carried out on a single PC in [19]. Even with a group of PCs connected to a single supply, changing the system frequency from 49.5Hz to 50.5Hz has almost no effect on the generated harmonics as shown in Figs. 9 and 10. However, increasing the loads decreases THD_i while increases THD_v.

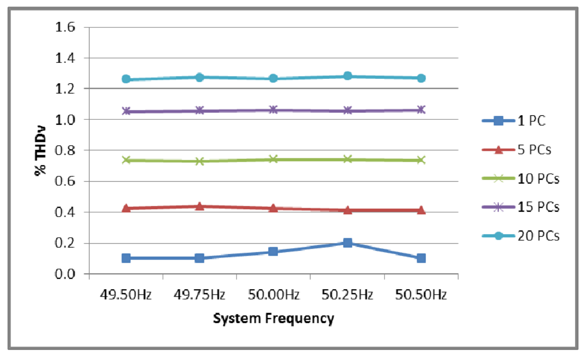

Figure 9. THD_v vs. frequency variation

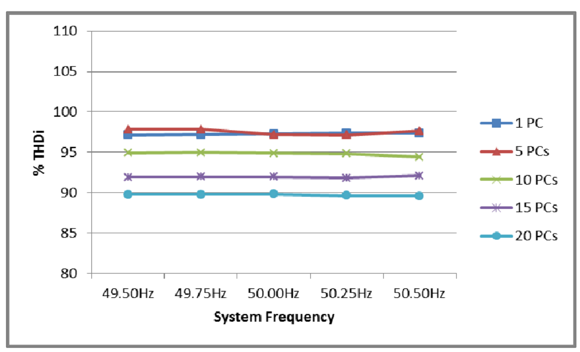

Figure 10. THD_i vs. frequency variation

D. Attenuation Effect

Although many papers have considered the attenuation effect on their studies [6-10]; however, in this research study, a group of more than 20 PCs was turned on one by one to assess the attenuation effect when they are fed with/without the Chroma power supply. THD_v and THD_i follow the expected trend of increasing voltage distortions with increasing the load, while current distortions decrease. In Figs. 11 and 12, if the Chroma power supply is not used, THD_v and THD_i curves are not smoothly increasing or decreasing because the background distortion of the power supply is not fixed. However, THD_v and THD_i increases and decreases in a systematic way when a Chroma power supply is used. Figs. 11 and 12 show that a change current THD will correspond to an inverse change in the voltage THD.

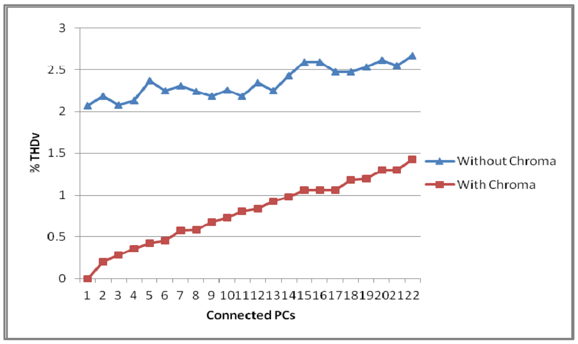

Figure 11. THD_v for a group of PCs

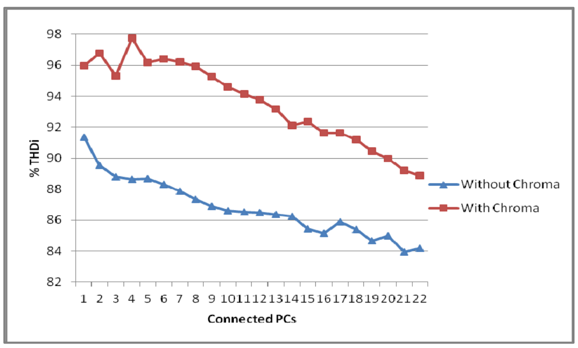

Figure 12. THD_i for a group of PCs

E. Diversity Effect

Many studies have been implemented to show the partial cancellation of harmonics due to different harmonics' phase angles for different nonlinear loads [6-8]. However in this research work, different case studies were carried out to assess the effects of upstream impedances considering both source and branch impedances as shown in Fig. 13. The five case studies input data is shown in Table 1.

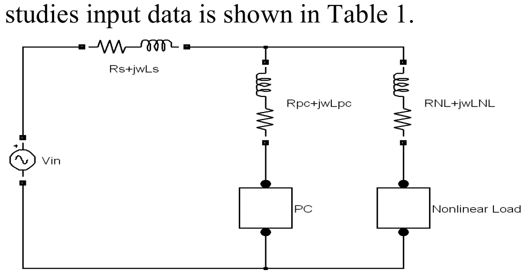

Figure 13. Nonlinear loads fed through same source impedance and different branch impedances

TABLE 1
SOURCE AND BRANCH IMPEDANCES' VALUES

Case	$R_S(\Omega)$, L_S (mH)	$R_{PC}(\Omega)$, L_{PC} (mH)	$R_{NL}(\Omega)$, L_{NL} (mH)
1	0.24, 0.21	0.1, 0.235	0.2, 0.292
2	0.24, 0.21	0.1, 0.11	0.1, 0.235
3	0.24, 0.21	0, 0	0, 0
4	0, 0	0.1, 0.235	0.2, 0.292
5	0, 0	0, 0	0, 0

Although many papers claim that this phenomenon affects harmonics noticeably, it is clear from Fig. 14 that changing one or both of the source and branch impedances within the practical limits has a minor effect on $\%THD_i$ of different system loadings, within less than 4% for the PC and laptop while less than 2% for the other system loadings. This means that it should not be expected that $\%THD_i$ will be decreased rapidly due to diversity effects when practical impedance values are considered. Fig. 14 also illustrates that not only THD_i, but also IHD_s are also almost fixed when the practical impedance values shown in Table 1 are considered.

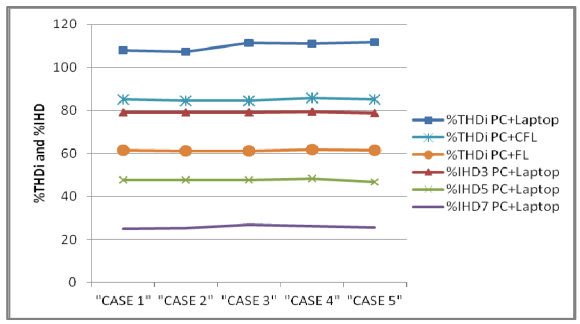

Figure 14. %THDi of different source and branch impedances. FL and CFL stand for Fluorescent and Compact Fluorescent Lamp, respectively.

III. Laptop Results Fed Via Different Power Systems

In the UK, most of the European countries and the USA, the customers are supplied by a 240V/50Hz, 230V/50Hz and 120V/60Hz power source, respectively. Most of the laptops nowadays are dual voltage which means that they are designed to operate and connect safely to a 110/120V or 220/240V power systems. Hence, in order to investigate the various power quality quantities associated with the laptop when it is supplied by different systems, the laptop was fed by 240V/50Hz, 230V/50Hz and 120V/60Hz systems.

It can be shown from Table 2 that all power quantities and harmonic indices of the laptop when it is supplied by a 240V/50Hz or 230V/50Hz supply are very close to each others. Hence, the 10V difference of the input voltage has almost minor effects on these quantities. However, when the laptop is fed by a 120V/60Hz power supply, its power quantities and harmonic indices are different. Due to the fact that this laptop has a control circuit to supply its internal circuits with a constant power, decreasing the 240V voltage by 100% results in increasing the drawn current by about 40% for the same input active power. To compensate the unequal decrease in voltage and increase in current for the same input power, the input PF should definitely increase.

TABLE 2
LAPTOP POWER QUANTITIES OF DIFFERENT SYSTEM

Index	Experimental Measurement		
	240V/50Hz	**230V/50Hz**	**120V/60Hz**
$\%THD_v$	0.10413	0.09924	0.20325
$\%THD_i$	269.585	267.789	219.891
1^{st}, %	69 (100)	71 (100)	132 (100)
3^{RD}, %	66 (95.8)	69 (96.2)	128 (97)
5^{th}, %	65 (93.9)	67 (94.3)	123 (93.1)
7^{th}, %	63 (91.2)	65 (91.4)	116 87.3
9^{th}, %	61 (87.9)	63 (88.0)	106 (80.0)
11^{th} , %	58 (83.7)	60 (83.5)	95 (71.7)
V, V_{rms}	239.952	229.936	119.971
I, A_{rms}	0.20653	0.21253	0.33994
P, W	16.585	16.5782	16.5934
N, var	46.7	45.9711	36.9883
S, VA	49.558	48.869	40.5398
P.F.	0.33465	0.33924	0.40904

In this case, it increases by 18%. Consequently, increasing the input current reduces its THD_i by 23%. Another important factor that helps in reducing THD_i is that PF is increased as they are inversely proportional to each other. On the other hand, changing the system supply to be a 120V/60Hz decreases nonactive power by about 26%. This is because nonactive power in general is directly proportional to the applied voltage. Hence, decreasing the voltage decreases the nonactive power. As a consequence, apparent power decreases by about 22%.

IV. CONCLUSION

Power systems harmonics are continuously varying due to many factors. In this paper the diversity, attenuation, frequency, impedance and voltage variation effects have been evaluated for the normal variation of parameters within a supply. Although system voltage, impedance and attenuation effect impact harmonics notably, system frequency and diversity effects have minor impacts on the produced harmonics produced by a cluster of PCs. Moreover, these factors are not isolated from each other. Rather, they occur simultaneously and their accumulative effects can be effectively high or some kind of harmonic compensation may occur. It is also proven that when a nonlinear device is supplied by different power systems, their generated harmonics and other power quantities will be different.

ACKNOWLEDGMENT

The authors would like to acknowledge King Abdulaziz University for their financial support of this PhD study.

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