Impact of Personal Computers and Compact Fluorescent Lamps on the Power Quality

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Abstract. The use of non-linear loads continues to expand in both industrial and commercial applications resulting in increased harmonic current distortions on the electrical system. This paper presents the simulation modeling of a personal computer (PC) and a compact fluorescent lamp (CFL), by using ATPDraw, as non-linear loads, which are continually using for both domestic and industrial applications and which can be considered as a source of harmonics and that results in power quality deterioration. The interest in this paper is focused on estimating the harmonics, that may exist in the current waveform when the PCs and CFLs are connected to the power supply and on estimating the excessive losses in low voltage line, where the results presented show that the use of these kinds of loads increased the level of excessive losses.

Keywords: PC, CFL, non-linear load, harmonics, excessive losses, power quality.

1 INTRODUCTION

Recently the interest has been growing to deal with the problems related to the subject of electromagnetic compatibility (EMC), which studies the interference between the different electrical appliances and their negative effects on the power quality. Negative reverse effects in general is called electromagnetic disturbance. Definitions of electromagnetic disturbance types may differ from author to author, specially between electronics and electrical engineers, but in common they are (James, 1994) outages (interruptions), surges (lightning or switching surges), undervoltage (voltage drop), harmonics, voltage sags, voltage swell and overvoltage. Harmonics has received special attention as one of the largest sources of electromagnetic disturbance as they generate voltages with frequencies different from the network frequency or absorbs currents with a non-sinusoidal waveform.

Among of the sources of harmonics there are PCs, CFLs, copiers, fax machines, TV sets, and any equipment that contains a switch mode power supply that uses the neutral of a third-phase, four-wire power system for its connection. The harmonic currents may lead to overheated wiring and panel boards, false tripping of protective devices (such as circuit breakers), humming of transformers and motors. In steady running conditions the electrical appliance does not always behaves as a non-linear load, but in switching-on phase, because of the inrush starting current, it always makes negative effects to the supply network and also to the other electrical appliances connected to the point of common coupling (PCC).

This paper presents the implications for distribution networks for widespread use of PCs and CFLs in terms of losses and power quality. In order to quantify the effects of the use of PCs and CFLs simulation models of PCs and CFLs are applied by using ATPDraw (H. K. Høidalen, 2012).

2 LOSSES DUE TO HARMONICS

The calculation of losses in power systems under purely sinusoidal conditions is straightforward because it is based in conventional power flow that assume linear impedances throughout the system. The increasing waveform distortion in power systems due to the widespread use of nonlinear loads requires losses to be calculated using more suitable techniques. Here it is important to remember that harmonic currents increase the rms or total effective load current. The rms current considering the harmonics is given by (Francisco, 2006) (Walter, 1995) as follows:

$$I_{rms} = \sqrt{I_{1,rms}^2 + \sum_{h=2}^{n} I_{h,rms}^2} \tag{1}$$

Where Ih,rms is the current at any harmonic order (h). I1,rms refers to the fundamental harmonic.

The total harmonic distortion (THD) which is the harmonic index is given by (IEEE definition) (Francisco, 2006) as:

$$THD = \frac{\sqrt{\sum_{h=2}^{n} I_{h,rms}^2}}{I_{1,rms}} \tag{2}$$

and the relationship between the rms current and the total harmonic distortion of the current is:

$$I_{rms} = I_{1,rms}\sqrt{THD^2 + 1} \tag{3}$$

This small increase in current above the rms current will produce increased losses, ΔP, relative to the case in which current contained no harmonics.

The power factor of the single-phase system PF can be defined as (K. Deželak, 2012):

$$PF = \frac{P}{U_{rms} I_{rms}} \tag{4}$$

The rms value of the current I_u, which is indispensable for energy transmission (L. S. Czarnecki, 1990), can be expressed as:

$$I_u = I_{rms} PF \tag{5}$$

The square of the power factor, ($1/PF^2$) as in equation (6), could be used as a measure for the excessive transmission losses $P_{ex,loss}$, where $P_{r,loss}$ indicates to the transmission losses which cannot be avoided (RI^2) (G. Štumberger, 2006).

$$P_{ex,loss} = P_{r,loss}\left(\frac{1}{PF^2} - 1\right) \tag{6}$$

The rms value of the current I_{ort}, which does not contribute to the active power is calculated as (L. S. Czarnecki, T. Swietlicki, 1990) (L. S. Czarnecki, 1990):

$$I_{ort} = \sqrt{I_{rms}^2 - I_u^2} \tag{7}$$

It is important to control the voltage drop induced by inrush current in a selected part of the supply transmission line, if it overreached the tolerance value 10%, according to IEC 60038, it will be necessary to change the conductor size, because the voltage drop depends on the material and diameter of the conductor.

3 PERSONAL COMPUTERS (PCs)

Personal computers are one of the most widely used electronic loads in modern life. It produces harmonic current especially when there is a large concentration of them in a distribution system. It utilizes the switch mode power electronics technology which draws highly non-linear currents that contain large amounts of third and higher order harmonics. A switch mode power supply (SMPS) has a large capacitor which maintains approximately constant voltage for the DC bus in the power supply. A typical PC load model uses SMPS and comprises of a full wave rectifier, a DC storage capacitor (C), a diode bridge resistance, R and a series RFI choke (Radio Frequency Interference) which is represented by an inductance L (C. Venkatesh, 2008). The proposed appropriate PC model simulated by ATPDraw is shown in Fig. 1.

A typical desktop computer uses about 65-250 W, add another 15-70 W for LCD monitor, or about 80 W for an old-school 17" CRT, while laptop computers use about 15-60 W (Michael). A computer with electronic switching supplies of a power about 350 W has nominal current approximately about 2 A and the inrush current may reach to 30 times larger (Břetislav 2002). Typical current waveform of a personal computer with I_{rms}=1.64 A has a total current harmonic distortion of 130% (Ir. Martin).

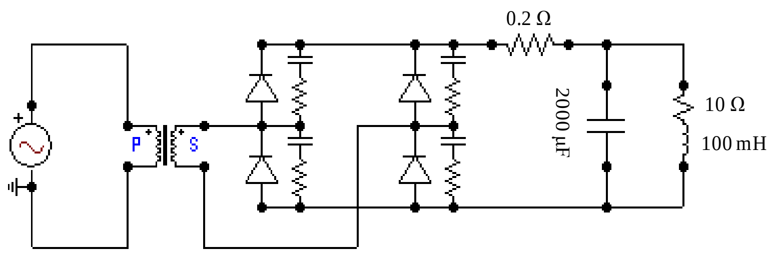

Fig. 1 Model of a PC

4 COMPACT FLUORESCENT LAMPS (CFLs)

The CFLs appeared in early 80's as a replacement of the traditional incandescent lamp (M. Abbaspour, 2009). CFLs provide significant energy savings over incandescent lighting, resulting in promotion as a part of energy saving programs at many electric utilities (R. Dwyer, 1995). The main concern associated with CFL is related with high levels of harmonic current distortion and consequently the impacts on a distribution system (A. E. Emmanuel, 1992). Power factors of CFLs could be even lower than 60 %, that could increase the power losses more than twice that of the linear loads (K. Deželak, 2012) (T. S. Key, 1996).

The CFL harmonic performance varies greatly with the topology of its power factor correction circuit. Therefore, there is a compromise between the generation of harmonics and cost, and often CFL life-time. Due to the price competition, manufacturers have introduced the simplest ballast design with neither harmonic filter nor power factor correction circuit. It usually has very high harmonic current levels, which depends on the size of the capacitor and front resistor, but is the cheapest to manufacture. The current THD is normally from 110% up to 200% (K. Deželak, 2012). A general simulation model of CFL is shown in Fig. 2. With a nominal rating of 20 W rectifier with a capacitor filtering circuit, this model is adequate to perform a detailed analysis of CFLs' external harmonic behaviour as this is the most common size and its current may has a THD obout 110%.

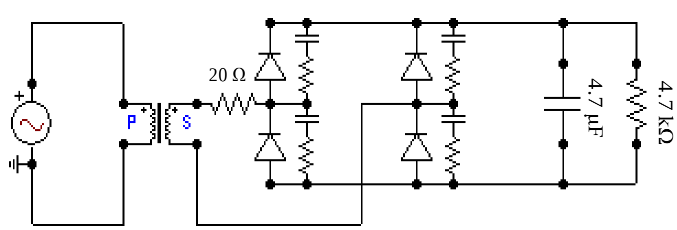

Fig. 2 Model of a CFL

5 RESULTS AND DISCUSSION

5.1 PCs

Time dependent voltage and currents of the PCs are shown in Fig. 3 and 4 for connection 1, 5 and 10 PCs, where the difference will occur in magnitudes only. The harmonic content of the current, listed in Table 1, is obtained from FFT analysis of the PC current and the rms frequency spectrum is shown in Fig. 5. From Table 1 and the current waveform it is clearly seen that the current is nonlinear and has 76.95% THD. The significant harmonics are the 3th with magnitude of 55.37% of the total I_{rms}, the 5th with 23.82%, the 7th with 5.09%, The 9th with 5.44% and the 11th with 2.70%.

The value of power factor for the 1PC, CPU and monitor with rated power about 100 W, where the supply voltage V=230 V and I_{rms}=0.741 A is 0.5867 which is very low and that will leave impact on the excessive transmission line losses.

For the evaluation of the excessive transmission line losses, with proposed resistance about 0.1 Ω, the equations (5-7) are applied and the results are listed in Table 2 below and in Fig. 6, where Pr,loss is calculated as ($R \times I_{rms}^2$). The ratio of the excessive transmission losses Pex,loss to the transmission losses which cannot be avoided Pr,loss is equal to 1.905.

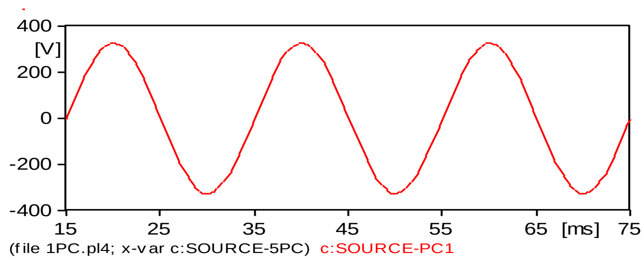

Fig. 3 Time dependent voltage signal of PCs

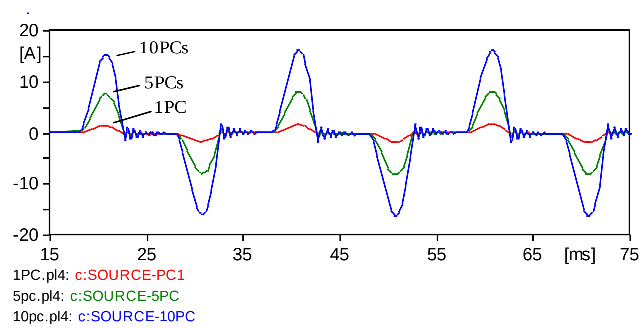

Fig. 4 Time dependent current signals of PCs

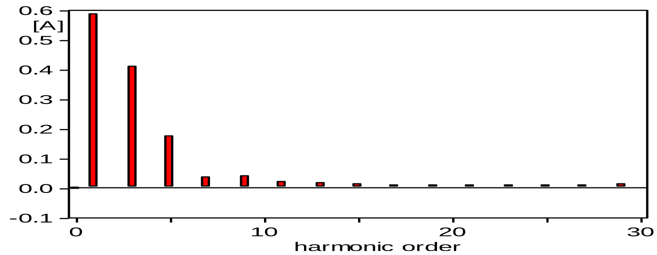

Fig. 5 Harmonic spectrum of the rms current for 1PC

Table 1. Harmonic current of the PCs

h	$I_{h,rms}$ (A)	p.u. of I_{rms} (%)	h	$I_{h,rms}$ (A)	p.u. of I_{rms} (%)	h	$I_{h,rms}$ (A)	p.u. of I_{rms} (%)
1	0.5873	79.25	11	0.0200	2.70	21	0.0089	1.21
2	0.0006	0.08	12	0.0001	0.02	22	0.0002	0.03
3	0.4103	55.37	13	0.0185	2.50	23	0.0095	1.28
4	0.0003	0.04	14	0.0002	0.03	24	0.0002	0.03
5	0.1765	23.82	15	0.0133	1.79	25	0.0087	1.17
6	0.0007	0.10	16	0.0003	0.03	26	0.0002	0.02
7	0.0378	5.09	17	0.0113	1.53	27	0.0108	1.46
8	0.0005	0.07	18	0.0001	0.02	28	0.0002	0.03
9	0.0403	5.44	19	0.0103	1.39	29	0.0124	1.67
10	0.0001	0.02	20	0.0001	0.02	30	0.0004	0.06
THD=76.95 %								

Table 2. Losses due to PCs harmonics

No. of PCs	I_{rms} (A)	Pr,loss (W)	Pex,loss (W)	Iu (A)	Iort (A)
1	0.741	0.0549	0.1046	0.4348	0.6001
5	3.7051	1.3728	2.6150	2.1739	3.0004
10	7.4103	5.4912	10.4601	4.3478	6.0007

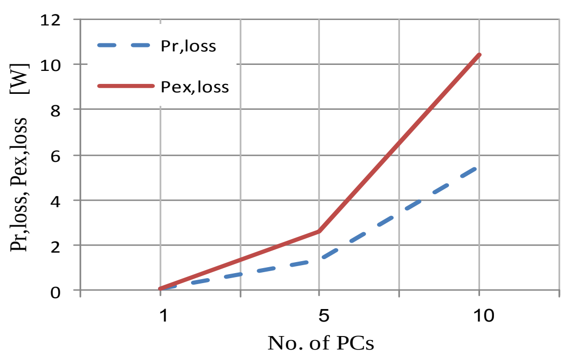

Fig. 6 Losses in low voltage single-phase line due to PCs

Triplens become an important issue for grounded-wye systems with current flowing on the neutral. Typical problems induced by triplens are overloading the neutral and telephone interference. Triplens (h=3, 9, 15, 21,… or 6k+3, for k=0,1,2,…) are generally zero sequence (Roger, 2004). The rms valuse of triplens are listed in Table 3 below.

Table 3. rms values of triplens in (A)

No. of PCs	3ed	9th	15th	21st	27th
1	0.4103	0.0403	0.0133	0.0089	0.0108
5	2.0515	0.2016	0.0665	0.0447	0.0541
10	4.1030	0.4032	0.1330	0.0894	0.1082

Since the PCs are connected line-to-neutral in a 3-phase system, the neutral current In is approximately equal to three times the vector sum of the triplen harmonic currents flowing in each phase (Francisco, 2006) (M. H. Shwehdi, 2012), thereby:

$$I_{n,1PC} = \sqrt{I_3^2 + I_9^2 + I_{15}^2 + I_{21}^2 + I_{27}^2} = 0.4127 \text{ A}$$

This value is only the portion of 1PC and 1-phase only. For 5PCs in 1-phase the value of $I_{n,5PC}$=2,0636 A and for 10PCs in 1-phase $I_{n,10PC}$=4,1273 A. For the 3-phase system, with assumption that the same number of PCs is connected to each phase, the neutral current will be for 1PC ($3I_{n,1PC}$=1.2382 A), for 5PCs ($3I_{n,5PC}$=6.191 A) and for 10PCs ($3I_{n,10PC}$=12.382 A). but the ratio of In to the I_{rms} will always equal to 0,557.

5.2 CFLs

By using the above analysis the source voltage and the current waveforms are shown in Fig. 7 and 8 for connection 1, 5 and 10 CFLs. The harmonic content of the current is listed in Table 4 and the rms frequency spectrum is shown in Fig. 9. The current has 108.14% THD and the significant harmonics are the 3th with magnitude of 47.24% of the total I_{rms}, the 5th with 34.59%, the 7th with 22.89%, The 9th with 18.55%, the 11th with 19.52%, the 13th with 18.76%, the 15th with 14.72%, the 17th with 9.25% and the 19th with 5.1%. The value of the power factor, where the supply voltage V=230 V and I_{rms}=0.1528 A is 0.5692.

The excessive transmission line losses are calculated as above and the results are listed in Table 5 below and in Fig. 10. The ratio of the excessive transmission losses $P_{ex,loss}$ to the transmission losses which cannot be avoided $P_{r,loss}$ is equal to 2.087.

The neutral current for 1CFL is equal to:

$$I_{n,1CFL} = \sqrt{I_3^2 + I_9^2 + I_{15}^2 + I_{21}^2 + I_{27}^2} = 0.081 \text{ A}$$

For 5CFLs in 1-phase $I_{n,5CFL}$=0,4048 A and for 10CFLs in 1-phase $I_{n,10CFL}$=0,8097 A. For the 3-phase system, the neutral current for 1CFL ($3I_{n,1CFL}$=0.243 A), for 5CFLs ($3I_{n,5CFL}$=1.2145 A) and for 10CFLs ($3I_{n,10CFL}$=2.429 A). The ratio of I_n to the I_{rms} will always equal to 0,53.

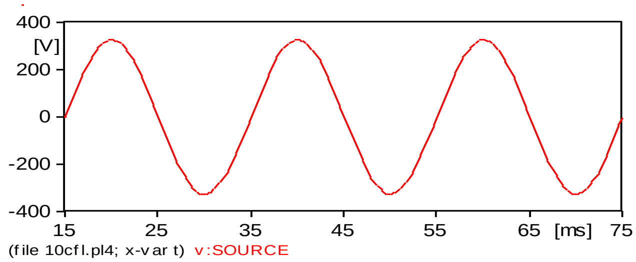

Fig. 7 Time dependent voltage signal of CFLs

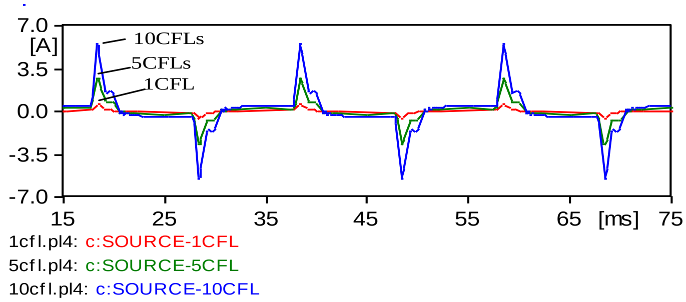

Fig. 8 Time dependent current signals of CFLs

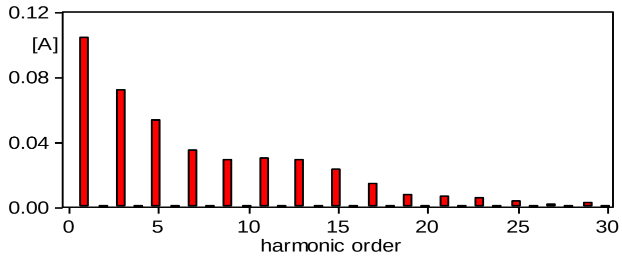

Fig. 9 Harmonic spectrum of the rms current for 1CFL

Table 4. Harmonic current of the CFLs

h	$I_{h,rms}$ (A)	p.u. of I_{rms} (%)	h	$I_{h,rms}$ (A)	p.u. of I_{rms} (%)	h	$I_{h,rms}$ (A)	p.u. of I_{rms} (%)
1	0.1037	67.89	11	0.0298	19.52	21	0.0059	3.84
2	0.0001	0.03	12	0.0002	0.15	22	0.0001	0.03
3	0.0722	47.24	13	0.0287	18.76	23	0.0049	3.24
4	0.0001	0.08	14	0.0002	0.14	24	0.0001	0.04
5	0.0529	34.59	15	0.0225	14.72	25	0.0030	1.97
6	0.0002	0.14	16	0.0002	0.15	26	0.0001	0.06
7	0.0350	22.89	17	0.0141	9.25	27	0.0018	1.17
8	0.0003	0.18	18	0.0002	0.14	28	0.0001	0.05
9	0.0283	18.55	19	0.0078	5.10	29	0.0022	1.43
10	0.0003	0.17	20	0.0001	0.09	30	0.0000	0.02
THD=108.14 %								

Table 5. Losses due to CFLs harmonics

No. of CFLs	I_{rms} (A)	$P_{r,loss}$ (W)	$P_{ex,loss}$ (W)	I_u (A)	I_{ort} (A)
1	0.1528	0.0023	0.0049	0.087	0.1256
5	0.7639	0.0584	0.1218	0.4348	0.6281
10	1.5278	0.2334	0.4872	0.8696	1.2562

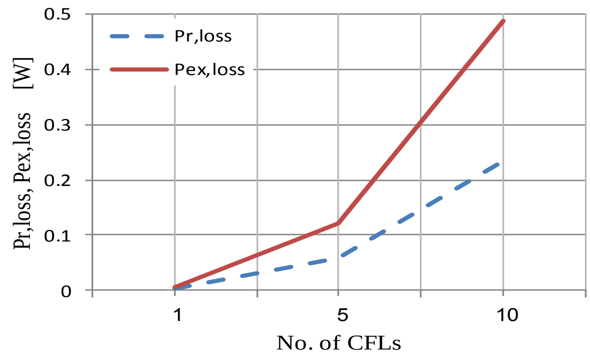

Fig. 10 Losses in low voltage single-phase line due to CFLs

Table 6. rms values of triplens in (A)

No. of CFLs	3ed	9th	15th	21st	27th
1	0.0722	0.0283	0.0225	0.0059	0.0018
5	0.3609	0.1417	0.1125	0.0294	0.0089
10	0.7217	0.2835	0.2250	0.0587	0.0178

5.3 Combinations PCs and CFLs

In the case of operating the PCs and CFLs by the proposed models in different combinations the results of the impact on the power factor and on the excessive transmission line losses gave interesting values. The combinations were 1PC+1CFL, 5PCs+5CFLs and 10PCs+10CFLs. The usage of these combinations leads to power factor improvement and consequently to the lowest transmission line losses.

The harmonic content of the current, listed in Table 7, and the rms frequency spectrum, shown in Fig. 11, illustrate the results of the combination 1PC+1CFL, whereas the other combinations will differ only in magnitudes. The THD of the current decreased to 65.93%, where for the PC was 76.95% and 108.14% for the CFL. The value of the power factor for all combinations is 0.66, which is better than the previous calculations. The significant harmonics are the 3th with magnitude of 51.27% of the total I_{rms}, the 5th with 15.67%, the 7th with 8.82%, the 11th with 4.13% and the rest of the harmonics are less than this value.

The excessive transmission line losses, listed in Table 8 below and in Fig. 13, confirm that the losses go down. The ratio of the excessive transmission losses $P_{ex,loss}$ to the transmission losses which cannot be avoided $P_{r,loss}$ is equal to 1.2874. The neutral current is listed in Table 9, where the ratio of I_n/I_{rms} will always equal to 0,5143.

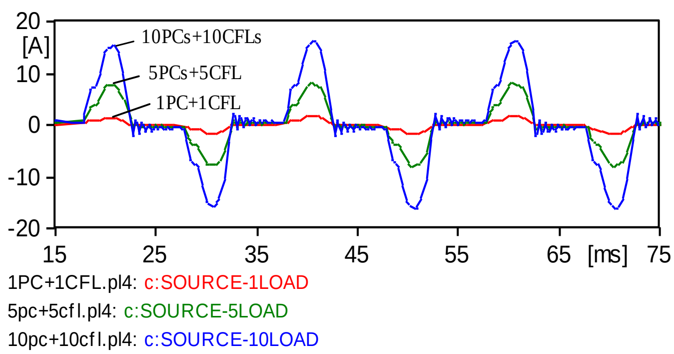

Fig. 11 Time dependent current signals of 1PC+1CFL

Fig. 12 Harmonic spectrum of the rms current for 1PC+1CFL

Table 7. Harmonic current of the combination 1PC+1CFL

h	$I_{h,rms}$ (A)	p.u. of I_{rms} (%)	h	$I_{h,rms}$ (A)	p.u. of I_{rms} (%)	h	$I_{h,rms}$ (A)	p.u. of I_{rms} (%)
1	0.6588	83.49	11	0.0418	5.30	21	0.0148	1.87
2	0.0005	0.07	12	0.0001	0.02	22	0.0002	0.02
3	0.4046	51.27	13	0.0326	4.13	23	0.0050	0.63
4	0.0004	0.05	14	0.0004	0.06	24	0.0002	0.03
5	0.1237	15.67	15	0.0157	1.99	25	0.0113	1.44
6	0.0006	0.07	16	0.0002	0.03	26	0.0002	0.02
7	0.0696	8.82	17	0.0249	3.15	27	0.0091	1.15
8	0.0003	0.04	18	0.0002	0.03	28	0.0003	0.03
9	0.0218	2.76	19	0.0025	0.32	29	0.0145	1.84
10	0.0004	0.05	20	0.0002	0.02	30	0.0004	0.05
THD=65.931 %								

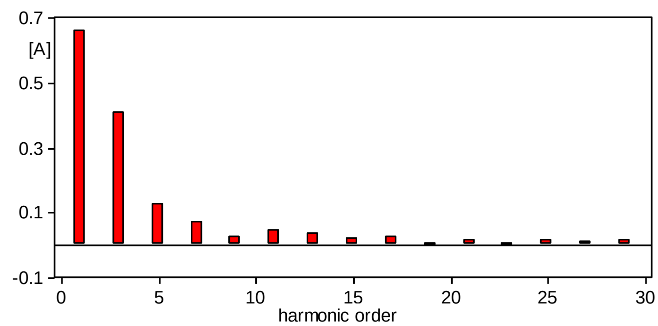

Table 8. Losses due to PCs+CFLs harmonics

Combination	I_{rms} (A)	$P_{r,loss}$ (W)	$P_{ex,loss}$ (W)	I_u (A)	I_{ort} (A)
1PC+1CFL	0.7891	0.0623	0.0802	0.5217	0.592
5PCs+5CFLs	3.9454	1.5566	2.004	2.6087	2.9599
10PCs+10CFLs	7.8909	6.2266	8.0163	5.2174	5.9199

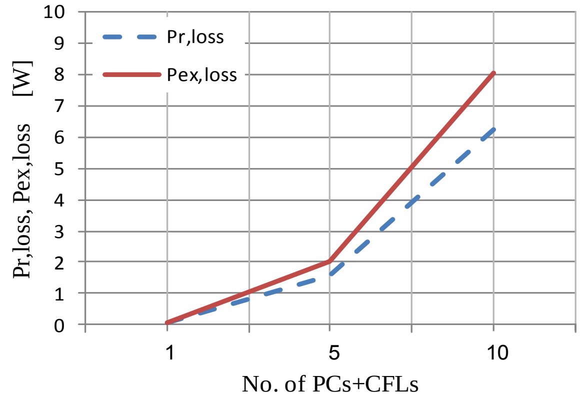

Fig. 13 Losses in low voltage single-phase line due to PCs+CFLs

Table 9. rms values of triplens in (A)

Combination	3ed	9th	15th	21st	27th	I_n (A) 1-phase	I_n (A) 3-phase
1PC+1CFL	0.4046	0.0218	0.0157	0.0148	0.0091	0.4059	1.2176
5PCs+5CFLs	2.0230	0.1090	0.0787	0.0740	0.0455	2.293	6.088
10PCs+10CFLs	4.0460	0.2180	0.1574	0.1479	0.0911	4.0586	12.176

6 CONCLUSION

This paper presents the simulation modeling of a personal computer and a compact fluorescent lamp by using ATPDraw to estimate excessive losses in low voltage line due to the harmonics generated by these types of non-linear loads. The rms values of the current and power factors must be determined to define these losses in the single phase systems. According to the results, it may be concluded that the excessive losses can reach values about 2 times higher in comparison with the losses that could not be avoided for both tow loads due to the lower value of the power factor. The results clarified that the combination of diffrenet loads of different power factors could even improve the value of power factor and consequently to the lowest transmission line losses. As for the harmonics of the current all results gave THDs more than the 5% limit set by IEEE-519 (IEEE Std, 1993). However, these models can be employed for harmonic analysis of a practical system and to design a suitable filter to mitigate harmonics in the distribution system.

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