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Impact of Compact Fluorescent Lamps on the Excessive Transmission Line Losses

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Abstract. The proposed paper deals with the calculation of the excessive transmission line losses caused by the compact fluorescent lamps. The number of the installed compact fluorescent lamps is rapidly increased, nowadays. Since such a lamps have large impact on the power factor as well as on the voltage and current total harmonic distortion their inclusion to the low voltage electrical grid should be fully investigated. In the paper the numerical model, with nonlinear characteristics of compact fluorescent lamps inclusion, is dealt. The numerically analysis is performed for four different compact fluorescent lamps available on the Slovenian market.

Key words

Compact fluorescent lamps, power factor, harmonic distortion, orthogonal decomposition

1. Introduction

Nowadays, the energy shortage on the one hand and the attempts to reduce emissions of greenhouse gases on the other hand, motivate us to address the question about the excessive transmission line losses. This work evaluates the excessive low voltage line losses [1] - [9] caused by the compact fluorescent lamps (CFLs), which represent nonlinear loads. Complete analysis is performed by an appropriate numerical model, where nonlinear characteristics of the CFLs loads could be easily included. The presented analysis is performed for four different CFLs available on the Slovenian market. The aforementioned model was confirmed by laboratory measurements.

The CFLs appeared in early 80's as a replacement of the traditional incandescent lamp [10]. CFLs provide significant energy savings over incandescent lighting, resulting in promotion as a part of energy saving programs at many electric utilities [11]. Their life span may be in some cases up to 20 times the life span of the classical incandescent lamps, while the heat losses are reduced up to 15 times. The main concern associated with CFL is related with high levels of harmonic current distortion and consequently the impacts of high distortion CFLs on a distribution system [12]. Power factors of CFLs could be even lower than 60 %, that could increase the power losses more than twice that of the linear loads [13]. All of that consequences influence the performance of other consumers connected to the electric power network.

Therefore, the main problem of the aforementioned nonlinear loads is that they can substantially increase excessive losses in the low voltage lines. These losses depend on load power and root mean square (RMS) values of current [1], [2]. For the higher RMS values of current these losses can increase and can reach more than 10 % of load power. For evaluation of excessive losses orthogonal decomposition of currents is applied [2], [3].

2. Orthogonal decomposition of currents

In this section the voltage and current of a single-phase system are defined together with the active power. They are used to define the RMS value of the current, which is indispensable for energy transmission, RMS value of the current, which does not contribute to the active power and the power factor of a single-phase system.

Let $u(t)$ and $i(t)$ stand for the voltage and line current of the single-phase system observed inside a selected time window $[0, T]$. Let us introduce the RMS values of voltage U_{rms} and current I_{rms} by (1) and (2), while the active power P is defined by (3), where t stands for the time.

$$I_{\mathrm{rms}} = \sqrt{\frac{1}{T}\int_0^T i(t)^2\,dt} \tag{1}$$

$$U_{\mathrm{rms}} = \sqrt{\frac{1}{T}\int_0^T u(t)^2\,dt} \tag{2}$$

$$P = \frac{1}{T}\int_0^T i(t)u(t)\,dt \tag{3}$$

The power factor of the single-phase system *PF* can be defined by (4).

$$PF = \frac{P}{U_{rms} I_{rms}} \qquad (4)$$

Considering (1) and (4), the RMS value of the current I_u, which is indispensable for energy transmission [1], can be expressed by (5).

$$I_u = I_{rms} PF \qquad (5)$$

The square of the power factor, actually $1/PF^2$ (6), could be used as a measure for the excessive transmission losses $P_{ex,loss}$, where $P_{r,loss}$ stands for the transmission losses which cannot be avoided [2].

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

The RMS value of the current I_{ort}, which does not contribute to the active power is given by (7) [1] - [3].

$$I_{ort} = \sqrt{I_{rms}^2 - I_u^2} \qquad (7)$$

3. Numerical model realization

This section deals with the numerical model realization, where calculated results were confirmed by an appropriate measurements. The main output results of numerical model are the RMS value of current, the power factor and the RMS value of the current indispensable for energy transmission.

A. Description of the applied compact fluorescent lamps

Table 1 shows the power *P*, current *I* and luminous flux *Φ* of the four different CFLs (CFL 1 - CFL 4), applied in this work and available on Slovenian market. That parameters are given by the CFLs manufacturer.

Table 1. The analyzed CFLs - manufacturer data.

CFL code	*P* [W]	*I* [A]	*Φ* [lm]
CFL 1	20	/	1155
CFL 2	20	0.160	1230
CFL 3	20	0.165	/
CFL 4	15	/	/

The first part of analysis represents the electrical characteristics measurements of all four different CFLs from Table 1. The time dependent current signals are shown in Fig. 1 (CFL 1 and CFL 2) and Fig. 2 (CFL 3 and CFL 4), while Table 2 shows, for each CFL, the RMS values of current I_{rms}, power *P*, power factor *PF* and RMS value of the current, which is indispensable for energy transmission I_u calculated by (1), (3), (4) and (5).

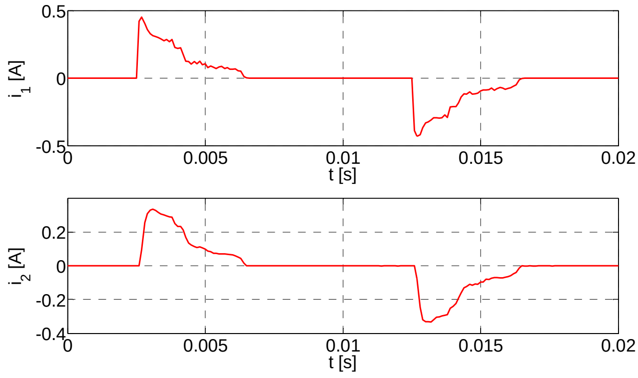

Fig. 1. Time dependent current signals for two (CFL 1 and CFL 2) CFLs.

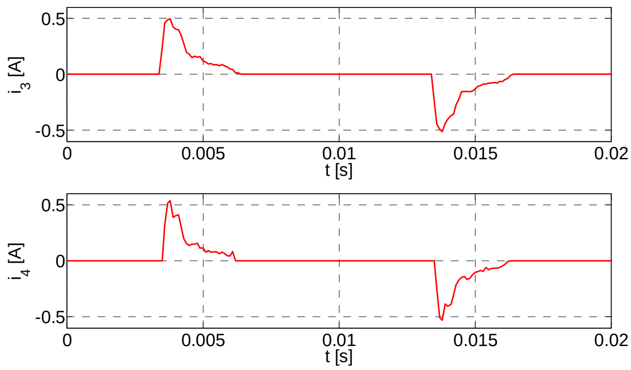

Fig. 2. Time dependent current signals for two (CFL 3 and CFL 4) CFLs.

Table 2. Calculated parameters of the analyzed CFLs.

CFL code	I_{rms} [A]	*P* [W]	*PF* [/]	I_u [A]
CFL 1	0.135	19.456	0.628	0.0847
CFL 2	0.12	17.788	0.647	0.0776
CFL 3	0.131	16.783	0.558	0.073
CFL 4	0.12	14.566	0.527	0.0632

After that, the measured characteristics were applied within the simulation model (Figs. 3, 6 and 8). In such a way, all four CFLs (Fig. 3), 3 × CFL 1 (Fig. 6) and CFLs combination (Fig. 8) were connected together in parallel.

B. Confirmation of numerical model - case 1

All four CFLs were connected in parallel where the RMS values of the current I_{rms}, the power *P*, the power factor *PF*, the RMS value of the current, which is indispensable for energy transmission I_u, the RMS value of the current, which does not contribute to the active power I_{ort} and excessive transmission line losses in a low voltage line are evaluated by an orthogonal decomposition of currents. The calculated results are shown in Table 3, while the time dependent current is shown in Fig. 4.

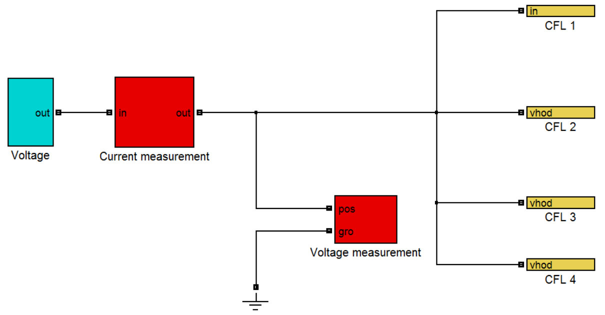

Fig. 3. Simulation model - CFLs (1., 2., 3., 4.) are connected in parallel.

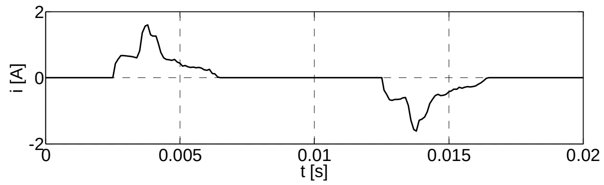

Fig. 4. Calculated time dependent current signal, when CFLs (1., 2., 3., 4.) are connected in parallel.

Table 3. Results for CFLs (1., 2., 3., 4.) connected in parallel (Fig. 3).

I_{rms} [A]	P [W]	PF [/]	I_u [A]	I_{ort} [A]
0.450	68.295	0.66	0.297	0.338

As (6) shows the excessive transmission line losses could be evaluated by power factor PF. If the transmission losses which cannot be avoided $P_{r,loss}$ are equal to 0.0203 W (the proposed ohmic resistance is 0.1 Ω), whilst the PF = 0.66, the excessive transmission line losses are equal to $P_{ex,loss}$ = 0.0263 W - ratio $P_{ex,loss}/P_{r,loss}$ is equal to 1.296.

The results from Table 3 were compared with the measured ones (Fig. 5) given in Table 4. Apart from the individual CFL currents (i_1, i_2, i_3 and i_4) and the total current i, Fig. 5 shows the measured per-unit voltage u_B.

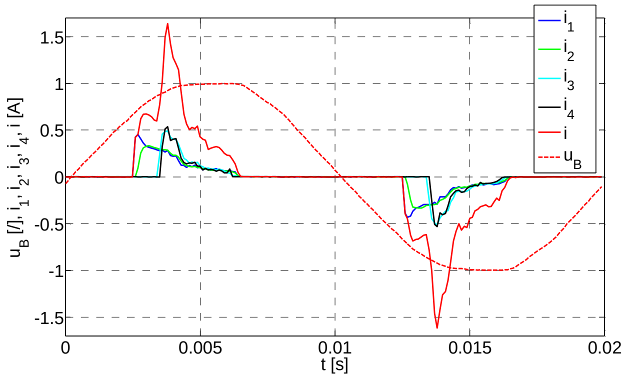

Fig. 5. Measured time dependent signals, when CFLs (1., 2., 3., 4.) are connected in parallel.

Table 4. Results for CFLs (1., 2., 3., 4.) connected in parallel (measured signals).

I_{rms} [A]	P [W]	PF [/]	I_u [A]	I_{ort} [A]
0.449	68.571	0.663	0.298	0.336

C. Confirmation of numerical model - case 2

In this subsection the three CFLs (3 × CFL 1) were connected in parallel - Fig. 6. The calculated results (RMS values of current I_{rms}, power P, power factor PF, RMS value of the current, which is indispensable for energy transmission I_u, RMS value of the current, which does not contribute to the active power I_{ort}) are shown in Table 5, while the measured results are given in Fig. 7 and Table 6. In Fig. 7 i_{1a}, i_{1b}, i_{1c} stand for three currents valid for the three different CFLs type "CFL 1".

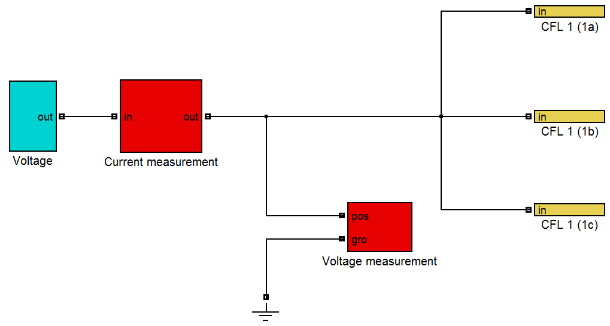

Fig. 6. Simulation model - CFLs (1a, 1b, 1c) are connected in parallel.

Table 5. Results for CFLs (1a, 1b, 1c) connected in parallel (Fig. 6).

I_{rms} [A]	P [W]	PF [/]	I_u [A]	I_{ort} [A]
0.404	58.233	0.627	0.253	0.315

If the transmission losses which cannot be avoided $P_{r,loss}$ are equal to 0.016 W (the proposed ohmic resistance is 0.1 Ω), whilst the PF = 0.627, the excessive transmission line losses are equal to 0.0247 W - ratio $P_{ex,loss}/P_{r,loss}$ is equal to 1.544.

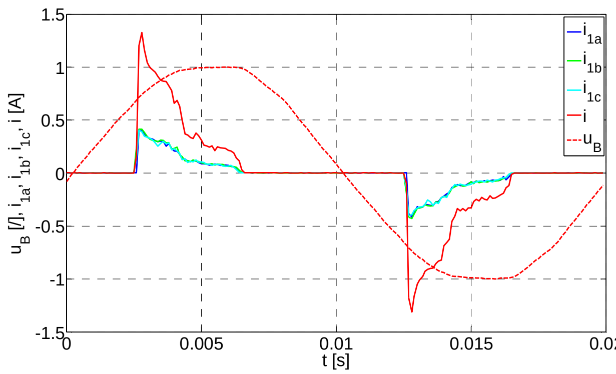

Fig. 7. Measured time dependent signals, when CFLs (1a, 1b, 1c) are connected in parallel.

Table 6. Results for CFLs (1a, 1b, 1c) connected in parallel (measured signals).

I_{rms} [A]	P [W]	PF [/]	I_u [A]	I_{ort} [A]
0.395	58.31	0.626	0.247	0.308

D. Confirmation of numerical model - case 3

In this subsection the CFLs combination (3 × CFL 1, 2 × CFL 2, 1 × CFL 3 and 1 × CFL 4) were connected in parallel - Fig. 8. The calculated results are shown in Table 7, while the measured results are given in Table 8.

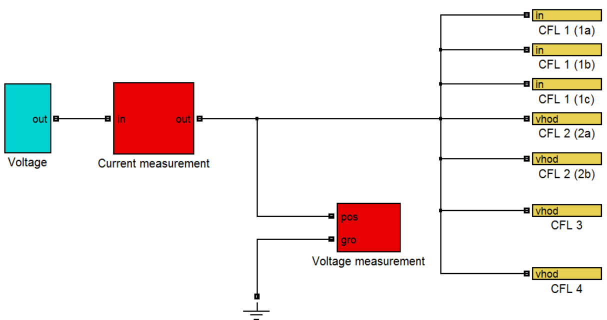

Fig. 8. Simulation model - CFLs (3 × CFL 1, 2 × CFL 2, 1 × CFL 3 and 1 × CFL 4) are connected in parallel.

Table 7. Results for CFLs (3 × CFL 1, 2 × CFL 2, 1 × CFL 3 and 1 × CFL 4) connected in parallel (Fig. 8).

I_{rms} [A]	P [W]	PF [/]	I_u [A]	I_{ort} [A]
0.809	124.808	0.671	0.543	0.600

In case of transmission losses which cannot be avoided $P_{r,loss}$ are equal to 0.065 W (the proposed ohmic resistance is 0.1 Ω) and the PF = 0.671, the excessive transmission line losses are equal to 0.0794 W - ratio $P_{ex,loss}/P_{r,loss}$ is equal to 1.221.

Table 8. Results for CFLs (3 × CFL 1, 2 × CFL 2, 1 × CFL 3 and 1 × CFL 4) connected in parallel (measured signals).

I_{rms} [A]	P [W]	PF [/]	I_u [A]	I_{ort} [A]
0.813	125.063	0.670	0.545	0.603

4. Results

In this section the impacts of CFLs, operated in different combinations, on the power factor and on the excessive transmission line losses are investigated by the proposed model. Firstly, 8 × CFL 1 (Fig. 9, Table 9), secondly 8 × CFL 3 (Fig. 10, Table 10), while finally 4 × CFL 1 and 4 × CFL 3 (Fig. 11, Table 11) were connected in parallel.

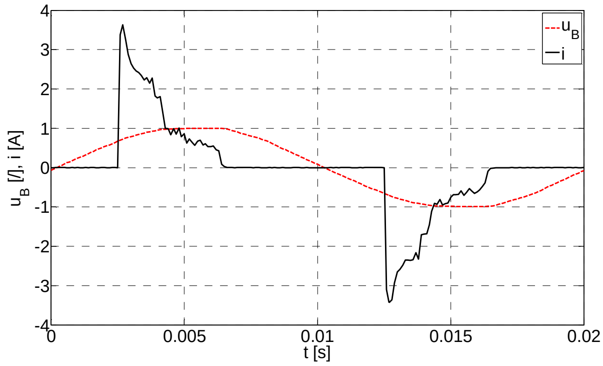

Fig. 9. Calculated time dependent signals, when CFLs (8 × CFL 1) are connected in parallel.

Table 9. Results for CFLs (8 × CFL 1) connected in parallel.

I_{rms} [A]	P [W]	PF [/]	I_u [A]	I_{ort} [A]
1.078	155.287	0.627	0.676	0.840

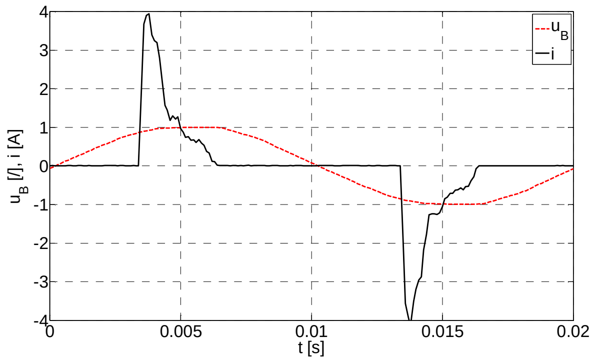

Fig. 10. Calculated time dependent signals, when CFLs (8 × CFL 3) are connected in parallel.

Table 10. Results for CFLs (8 × CFL 3) connected in parallel.

I_{rms} [A]	P [W]	PF [/]	I_u [A]	I_{ort} [A]
1.045	133.655	0.557	0.582	0.868

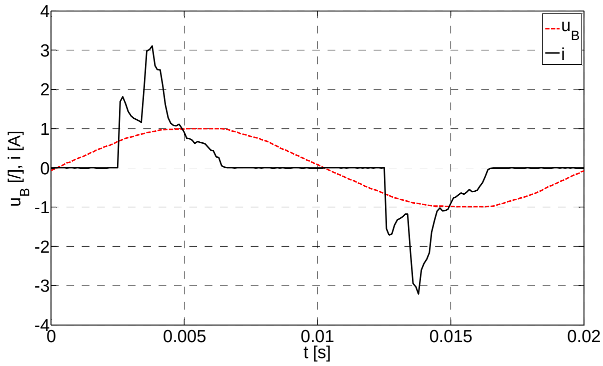

Fig. 11. Calculated time dependent signals, when CFLs (4 × CFL 1 and 4 × CFL 3) are connected in parallel.

Table 11. Results for CFLs (4 × CFL 1 and 4 × CFL 3) connected in parallel.

I_{rms} [A]	P [W]	PF [/]	I_u [A]	I_{ort} [A]
0.946	144.471	0.665	0.629	0.707

The excessive transmission line losses reach the higher value in case of 8 × CFL 3 ($P_{ex,loss}/P_{r,loss}$ = 2.223), while in case of 8 × CFL 1 aforementioned ratio $P_{ex,loss}/P_{r,loss}$ is reduced to 1.544. The combination usage (4 × CFL 1 and 4 × CFL 3) leads to power factor improvement and consequently to the lowest transmission line losses ($P_{ex,loss}/P_{r,loss}$ = 1.261).

5. Conclusion

This paper evaluates excessive low voltage line losses caused by the nonlinear loads represent by the compact fluorescent lamps. Generally to define these losses in the single-phase systems the RMS values of the current and power factor of entire system must be determined. Based on the presented results, we can conclude, that the excessive low voltage line losses can reach even 2.2 - 2.3 higher values in comparison of the transmission line losses that could not be avoided. It was shown that the several CFLs with the same characteristics mean no difference in the power factor value, while combination of different CFLs could even improve the value of power factor.

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