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Impact of compact fluorescent lamps on energy transmission losses and power quality

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Abstract. The compact fluorescent lamps (CFLs), called also saving bulbs, produce the same luminous flux as incandescent lamps (normal bulbs) (ILs), but require only 20 to 25 percents of the power required by the ILs. However, it is often neglected that CLFs behave as nonlinear loads, causing harmonic distortion of currents and voltages and additional losses related with the energy transmission. In the case study, this work evaluates the impact of CFLs on the power quality and increase of losses related with the energy transmission.

Key words: compact fluorescent lamps, power quality, total harmonic distortion, energy transmission losses, orthogonal decomposition of currents

1. Introduction

The energy shortage on one hand and global warming on the other hand, force us to reduce energy consumption and emissions of greenhouse gases. In the field of lighting the energy consumption can be reduced using compact fluorescent lamps (CFLs). The CFLs consume approximately 20 to 25 percents of the energy consumed by the incandescent lamps (ILs) (normal bulbs) to produce the same luminous flux. From the viewpoint of energy saving the advantages of CFLs are clear. However, the CFLs are nonlinear loads which increase total harmonic distortion of currents and voltages as well as transmission losses. In the case study, this work discusses the impact of CFLs on transmission losses and distortion of power quality. In order to perform the analysis orthogonal decomposition of currents in the time domain is applied.

2. Orthogonal decomposition of currents

Let $u_a(t)$, $u_b(t)$ and $u_c(t)$ be the voltages and $i_a(t)$, $i_b(t)$ and $i_c(t)$ be the currents of a three-phase system observed over a time interval $t \in [0,T]$, where they can be treated as continuous functions. In order to determine current indispensable for energy transmission, presented in the form of active power P, current vector $\mathbf{i}$ and voltage vector $\mathbf{u}$ are introduced by (1).

$$\mathbf{i} = \left[i_a(t) \;\; i_b(t) \;\; i_c(t) \right]^T , \quad \mathbf{u} = \left[u_a(t) \;\; u_b(t) \;\; u_c(t) \right]^T \quad (1)$$

The inner product of both vectors $(\mathbf{u},\mathbf{i})$ is given by (2):

$$(\mathbf{u},\mathbf{i}) = \frac{1}{T}\int_0^T \mathbf{u}^T \mathbf{i} \, dt = P \quad (2)$$

where P is the active power for the entire three-phase system. In the similar way squares of the current vector norm $\|\mathbf{i}\|^2$ and voltage vector norm $\|\mathbf{u}\|^2$ are introduced by (3) and (4), respectively:

$$\|\mathbf{i}\|^2 = (\mathbf{i},\mathbf{i}) = \frac{1}{T}\int_0^T \mathbf{i}^T \mathbf{i} \, dt = I_a^2 + I_b^2 + I_c^2 \quad (3)$$

$$\|\mathbf{u}\|^2 = (\mathbf{u},\mathbf{u}) = \frac{1}{T}\int_0^T \mathbf{u}^T \mathbf{u} \, dt = U_a^2 + U_b^2 + U_c^2 \quad (4)$$

where the squares of RMS values of currents and voltages in individual phases are denoted by I_a^2, I_b^2, I_c^2 and U_a^2, U_b^2, U_c^2.

The current vector $\mathbf{i}$ (1) can be decomposed into two orthogonal components defined in (5). The first one denoted with $\mathbf{i}_u$ is indispensable for energy transmission. It is aligned with the voltage vector $\mathbf{u}$. The second one denoted with $\mathbf{i}_{uo}$ is orthogonal to the voltage vector $\mathbf{u}$ and does not contribute to the active power P.

$$\mathbf{i}_u = \frac{P}{\|\mathbf{u}\|^2}\mathbf{u}\,, \quad \mathbf{i}_{uo} = \mathbf{i} - \mathbf{i}_u \tag{5}$$

The current vector components $\mathbf{i}_u$ and $\mathbf{i}_{uo}$ are orthogonal. Their inner product equals zero $(\mathbf{i}_u, \mathbf{i}_{uo})=0$, while the norms of vectors $\mathbf{i}$, $\mathbf{i}_u$ and $\mathbf{i}_{uo}$ are related by (6).

$$\|\mathbf{i}\|^2 = \|\mathbf{i}_u\|^2 + \|\mathbf{i}_{uo}\|^2 \tag{6}$$

The transmission losses in the electric lines are function of $\|\mathbf{i}\|^2$, while for the active power only current vector $\mathbf{i}_u$ is indispensable. The generalized power factor *PF* (7) is given as a ratio between norms of $\mathbf{i}_u$ and $\mathbf{i}$.

$$PF = \frac{\|\mathbf{i}_u\|}{\|\mathbf{i}\|} = \frac{\|\mathbf{i}_u\|\,\|\mathbf{u}\|}{\|\mathbf{i}\|\,\|\mathbf{u}\|} = \frac{|P|}{\|\mathbf{i}\|\,\|\mathbf{u}\|} \tag{7}$$

In the case of a single phase system, the definitions for the current vector $\mathbf{i}$ and voltage vector $\mathbf{u}$, given by (1), change to (8), which must be considered in (2) to (7).

$$\mathbf{i} = \left[i_a(t)\right], \quad \mathbf{u} = \left[u_a(t)\right] \tag{8}$$

3. Analysis

The transmission losses P_l in a single and in a three-phase system can be calculated by (9), where R and R_n the resistances of the line and neutral conductors, $\|i_n\|$ and $\|\mathbf{i}\|$ the norms (RMS values) of the neutral conductor current i_n and the current vector $\mathbf{i}$ (1).

$$P_l = R\|\mathbf{i}\|^2 + R_n\|i_n\|^2 \tag{9}$$

The *LF* (10) denotes the ratio between the transmission losses P_l and the load power *P*.

$$LF = \frac{P_l}{P} \tag{10}$$

4. Results

In the case study, the 4 wire cable with the wire impedance $Z = 0.2474 + j\,0.0415\ \Omega$ connects the single- or three-phase loads in the form of CLFs or ILs with the distribution transformer (150 kVA, 20/0.4 kV, Dyn5).

Tables I and II show load power, transmission losses, power factor and ratio *LF*, for the cases of single- and three-phase loads in the form of ILs and CFLs, which produce the same luminous flux. On the other hand Figs. 1 and 2 show transmission losses as a function of load power for single- and three-phase loads in the forms of ILs and CFLs.

Table I: Load power *P*, transmission losses P_l, power factor *PF* and ratio $LF = P_l/P$ for IL and CFL – single-phase load

	P (W)	P_l (W)	*PF*	*LF*
IL	92.083	0.1560	1.00	0.0017
CFL	19.009	0.0182	0.60	0.0010

Table II: Load power *P*, transmission losses P_l, power factor *PF* and ratio $LF = P_l/P$ for wye-connected ILs and CFLs

	P (W)	P_l (W)	*PF*	*LF*
IL	276.2306	0.1158	1.00	0.00042
CFL	56.7927	0.0266	0.60	0.00047

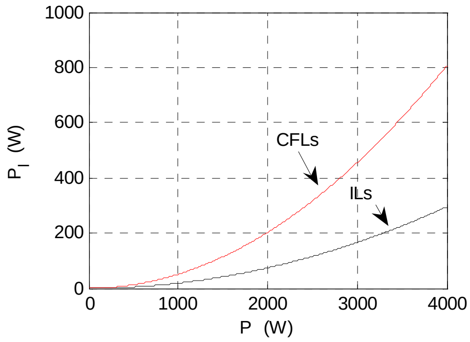

Figure 1: Single-phase load: transmission losses P_l given as a function of load power *P* for CFLs and ILs

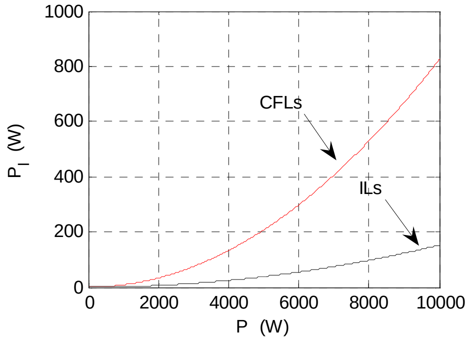

Figure 2: Three-phase load: transmission losses P_l given as a function of load power *P* for wye-connected CFLs and ILs

The results presented in Tables I and II and Figs. 1 and 2 show that the required power and transmission losses are much lower in the case of CLFs if the same luminous flux is required. However, when transmission losses are discussed with respect to the unit of load power, the ILs perform much better.

5. Conclusion

The results presented in this contribution clearly show that CFLs require only 20 to 25 percents of the power required by ILs to produce similar luminous flux. There is no doubt that CFLs can save a lot of energy. However, with the increasing power of CFLs installed in distribution networks, the energy transmission related losses, with respect to the unit of load power or unit of deliver energy, must be considered as well. From this viewpoint, at least in the presented case study, the CFLs' performances are bed. The power factor of 0.6 is very low. Combinations of nonlinear loads, like CFLs, computes, UPSs and similar devices, can make it even lower, which can substantially increase transmission losses. However, in the distribution networks the nonlinear and linear loads are normally combined and unbalanced. They all must be considered in the analysis, in order to obtain relevant evaluation of transmission losses.