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Calculation of excessive losses in low voltage line caused by computers

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Abstract. This work estimates excessive losses in low voltage line caused by nonlinear loads. Typical examples of nowadays nonlinear loads are computers, which numbers is especially increased in different types of companies as well as universities. In the case study the excessive losses in low voltage lines caused by the old and new computers are evaluated. The results presented show that the new technologies applied in the new generations of computers increased level of excessive losses in low voltage lines.

Key words: low voltage line, excessive losses, nonlinear load, computer, orthogonal current decomposition,

1. Introduction

This work evaluates excessive low voltage line losses in the single-phase and three-phase systems caused by computers which represent nonlinear loads. For evaluation of excessive losses orthogonal decomposition of currents [1] is applied. The nonlinear loads in the form of computers can substantially increase excessive losses in the low voltage lines especially in companies with a large number of simultaneously operating computers. These losses depend on load power and RMS values of current [2] – [5]. For higher RMS values of current these losses can increase and can reach more than 10% of load power. Nowadays, the energy shortage on one hand and the attempts to reduce emissions of greenhouse gases on the other hand, motivate use to address the question excessive losses caused by the computers which are not negligible. In the case study, this work evaluates excessive losses caused by the old and new generations of computers in the single-phase and three-phase low voltage lines.

2. Orthogonal decomposition of currents

Mathematical tool orthogonal decomposition of currents can be applied in single-phase systems likewise in three-phase systems [1], [6], [7]. This work deals with single-phase (one line current, one phase voltage) and three-phase (three line currents, three phase voltages) systems, where linear and nonlinear loads are considered.

A. Single-phase systems

Let $i(t)$ and $u(t)$ be the line current and voltage of a single-phase system observed inside a selected time window $[0, T]$. The RMS values of current I_{RMS} and voltage U_{RMS} are defined by (1) and (2), respectively:

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

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

where t stands for the time. In the same way the active power of a single-phase system can be calculated by (3).

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

Once the current and voltage RMS values and active power of a single-phase system are obtained, the power factor PF of a single-phase system can be calculated by (4) [7].

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

Current indispensable for energy transmission i_{u} and excessive losses in low voltage line due to the energy transmission P_{Exloss} can be calculated by (5) and (6), where P_{Rloss} stands for transmission line losses which cannot be avoid [7].

$$i_{\mathrm{u}} = I_{\mathrm{rms}} PF \tag{5}$$

$$P_{\mathrm{Exloss}} = P_{\mathrm{Rloss}} \left(\frac{1}{PF} \right)^2 \tag{6}$$

In case when the power factor of the single-phase system is equal to one, the current indispensable for energy transmission is equal to the line current, while the losses caused by to the energy transmission cannot be avoid.

B. Three-phase systems

In case of a three-phase system the situation is similar as in the case of a single-phase system. The only substantial difference represents the number of phases. Therefore, instead of power factor *PF* (4) the generalized power factor *PF*' [7] is defined by (7)

$$PF' = \frac{P'}{U'I'} \tag{7}$$

where *I*' and *U*' represent the equivalent RMS values of the three-phase currents (8) and voltages (9), while *P*' (10) stands for the active power of the three-phase system.

$$I' = \sqrt{I_{1\mathrm{rms}}^{\ 2} + I_{2\mathrm{rms}}^{\ 2} + I_{3\mathrm{rms}}^{\ 2}} \tag{8}$$

$$U' = \sqrt{U_{1\mathrm{rms}}^{\ 2} + U_{2\mathrm{rms}}^{\ 2} + U_{3\mathrm{rms}}^{\ 2}} \tag{9}$$

$$P' = P_1 + P_2 + P_3 \tag{10}$$

In (8) and (9) $I_{1\mathrm{rms}}$, $I_{2\mathrm{rms}}$, $I_{3\mathrm{rms}}$, $U_{1\mathrm{rms}}$, $U_{2\mathrm{rms}}$ and $U_{3\mathrm{rms}}$ denote the RMS values of current and voltage of individual phases calculated by equations (1) and (2), while in (10) P_1, P_2 and P_3 represent active powers of individual phases defined by (3). In the case of three-phase system the same equations for calculation of the current indispensable for energy transmission i_u and excessive losses in low voltage line P_{Exloss} (5) and (6) can be used as in the case of single-phase system. Only the generalized power factor *PF*' (7) must be applied instead of power factor *PF* (4).

3. Evaluation of excessive low voltage line losses

In this section the excessive transmission line losses in a low voltage line, actually cable, with length 200m, are evaluated by orthogonal decomposition of currents. The aforementioned 400 V low voltage cable supplies a university building with approximately 1100 computers. The evaluation is performed for two different cases. In the first case a single-phase system is applied to supply the computers while in the second case the three-phase supply is applied. Because the number of computers is the same in both cases it is obvious that the line current in the single-phase system is higher than one line current in the three-phase system. Therefore, it is expected higher values of excessive transmission line losses for single-phase system.

Figs. 1 and 2 show time dependent current and time dependent voltage signal of one computer producing by new technologies (“new” computer). Current signal is extremely nonlinear so the values of power factor calculated by (4) is very low (*PF* = 0.59).

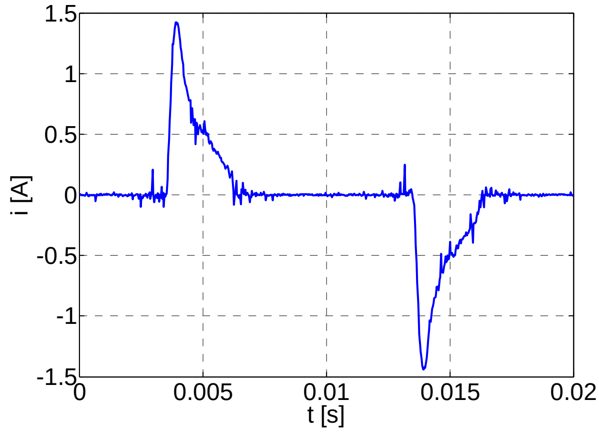

Fig. 1: Time dependent current signal of “new” computer.

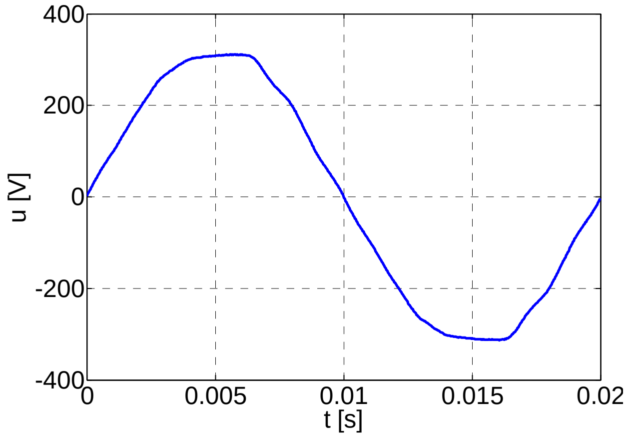

Fig. 2: Time dependent voltage signal of computer.

Fig. 3 shows single-phase load power applied by single-phase cable *P* as function of number of “new” computers *N*. This load power increases linear with the increasing number of computers. For *N* = 1100 the load power is *P* = 55573 W.

Besides load power, Fig. 3 shows losses in low voltage single-phase cable which cannot be avoid P_{Rloss} (for *N* =1100, P_{Rloss} = 5974 W) and excessive losses P_{Exloss} (for *N* =1100, P_{Exloss} = 17162 W) which appear due to the nonlinear load. Losses which cannot be avoided P_{Rloss} are calculated for completely ohmic resistance single-phase load where *PF* (4) equals 1.

Fig. 4 shows time dependent current signal of a few years old computer (“old” computer). The value of the power factor (4) is better than for the “new” computer and equals *PF* = 0.66.

The differences in excessive low voltage line losses determined for “old” and “new” computers (single-phase load) are shown in Fig. 5. As we had expected the values of excessive low voltage line losses are higher for the computers produced by new technologies. They are increased for 20% with respect to the old computers.

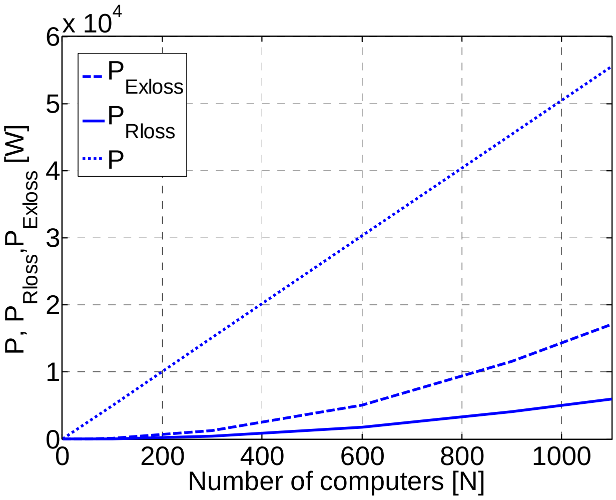

Fig. 3: Load power P, losses in low voltage single-phase cable which cannot be avoid P_{Rloss} and excessive losses P_{Exloss} which appear due to the nonlinear single-phase load.

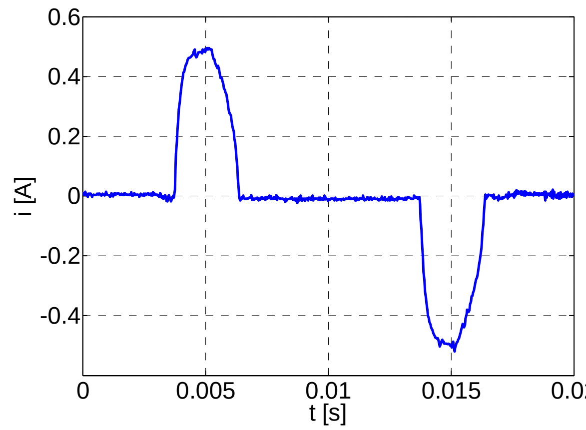

Fig. 4: Time dependent current signal of “old” computer.

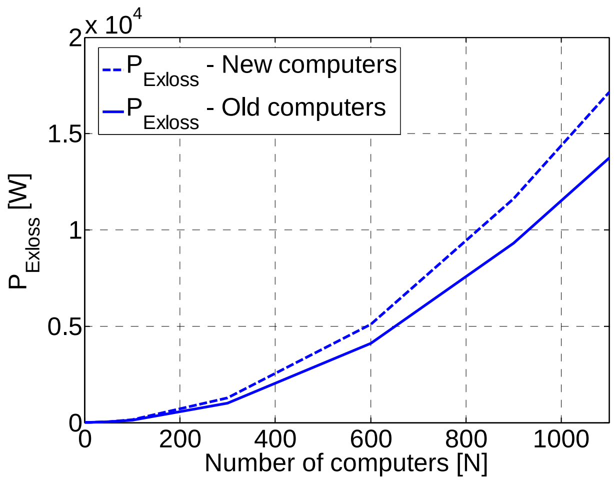

Fig. 5: Excessive losses which for the “new” and “old” computers in the case of single-phase load.

Fig. 6 shows three-phase load power P supplied by the three-phase cable given as a function of the number of “new” computers N. This load power increases linearly with the increasing number of supplied computers. Besides the load power, Fig. 6 shows losses in low voltage three-phase cable which cannot be avoid P_{Rloss} and excessive losses P_{Exloss} caused by the nonlinear three-phase load.

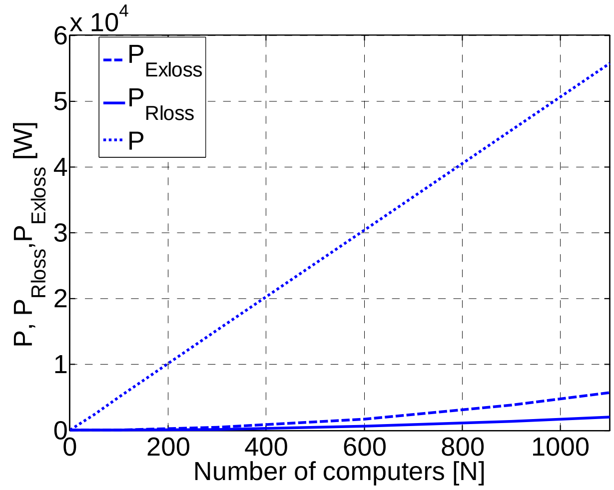

Fig. 6: Load power P, losses in low voltage three-phase cable which cannot be avoid P_{Rloss} and excessive losses P_{Exloss} caused by the nonlinear three-phase load.

The differences excessive low voltage line losses determined for the “old” and “new” computers (three-phase load) are shown in Fig. 7.

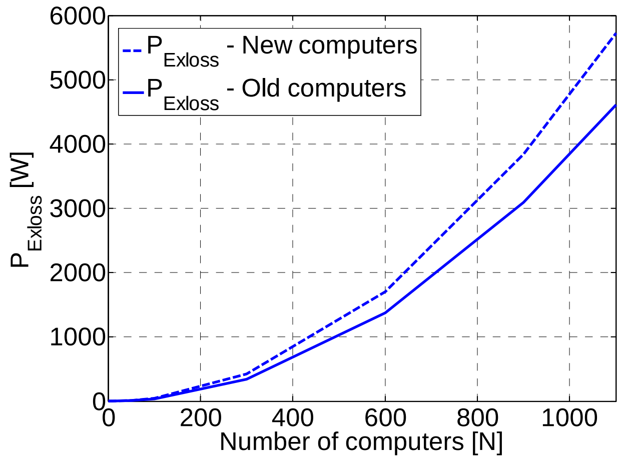

Fig. 7: Excessive losses determined for the “new” and “old” computers in the case of three-phase load.

Based on the comparison of results shown on Figs. 3, 5 and 6, 7, it is possible to conclude that the values of excessive low voltage line losses are lower for the three-phase system. This statement is true only when the three-phase and the single-phase low voltage lines supply the same load power.

The aforementioned statement is confirmed by the results shown in Fig. 8. It shows the comparison of losses which cannot be avoided and excessive losses in the low voltage cable for both, the single-phase and three-phase systems. Losses in Fig. 8 are shown in percentage of the load power P. These losses increase linearly with the increasing number of supplied computers. They reach higher values in case of single-phase system. This finding is understandable because for supplying the same load power with a single-phase system the line current must be much higher as line current in the case of three-phase system.

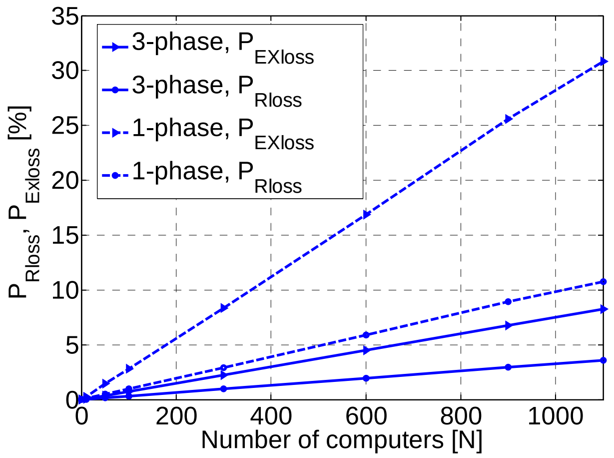

Fig. 8: Losses in low voltage cable which cannot be avoid and excessive transmission line losses for single-phase and three-phase systems.

4. Conclusion

This paper evaluates excessive low voltage line losses caused by the nonlinear computer loads. Generally to define these losses in the single-phase and three-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 30% of the load power. In the case when the same load power is supplied by the three-phase cable these losses reach more than three times lower value than in the case of a single-phase supply cable. Besides this we found out that computers produced by new technologies have worse power factor and higher low voltage line losses than computers produced by old technologies, which is a reason for concern.

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