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POWER LOSSES ANALYSIS IN LOW VOLTAGE DISTRIBUTION GRIDS. STUDY CASE

eng. Miron Anca, prof.dr.eng. Chindris Mircea, dr.eng. Cziker Andrei
Technical University of Cluj-Napoca, Power Systems Department
15, Daicoviciu St., 400020,
Romania

ABSTRACT

The paper deals with an issue of special interest for both suppliers and distributors of electrical energy: power losses in LV electric distribution grids.

At the moment, the distribution grids supply a great number of unbalanced and non-linear consumers, which bring about an unbalanced and non-sinusoidal operation state. This state has a major negative outcome: growth of power losses in electric lines and transformers belonging to the transmission and distribution systems. In the design stage of the electric grids, the power and energy losses calculus is performed considering a sinusoidal balanced functioning state. In the operation stage, this fact can generate the overloading of the active and neutral conductors or even the degradation of the entire network..

Keywords: power losses, low voltage distribution grid.

1. INTRODUCTION

The use of modern technologies, and the increasing use of power electronics have lead to an important increase of the number of electromagnetic disturbances sources; they cause an intense pollution of the electric grids, leading to a complex operating state: unbalanced and non-sinusoidal. For power utilities, the most important consequence is supplementary power losses in the electric grids. In addition, the issue of neutral voltage deviation, generating the rise of voltage in one ore two phases, must be carefully treated considering the possible incidents in the consumers' grids, directly supplied from the LV public distribution grid.

Power losses have an important role in the design and working stage of the electric grids. In the first case, power losses are calculated considering a sinusoidal and balanced operating state; in practice, this fact can cause the overloading of the electric lines, especially of the neutral conductor, leading to their wear down and even to their damage. The knowledge of real energy losses, considering the technical and functional characteristics of the electric grids and the pollution level of current and voltage waveforms, represents a desideratum in the design, operating and development stage; on the other hand, it is useful for establishing the grid characteristics and working state [1].

The paper analyzes the power losses issue in electric distribution grids operating in real states. Consequently, the relationships used to calculate the supplementary power losses considering the existence of non-sinusoidal and/or unbalanced states are described. The theoretical aspects are completed with a practical analysis of a typical urban distribution grid. The paper ends with a chapter of conclusions regarding the study case.

2. CALCULUS OF POWER LOSSES IN ELECTRIC DISTRIBUTION GRIDS

Power losses occur in all grid elements during the transmission and distribution stages of power flow. The level of energy losses ranges between 10% and 15% of the energy produced by the power plants, depending on the structure of the power network, working conditions, etc.

In balanced electric lines with three conductors operating with sinusoidal waves, the current flow through the line impedance $\underline{Z_L} = R + jX$ produces the following technological power losses:

$$\Delta P = 3 \cdot I^2 \cdot R\ [W]. \qquad (1)$$

In non-sinusoidal state, the existence of harmonic currents produces the rise of effective real current comparative to the fundamental component, and the growth of active energy and power losses. The mathematical relationship used in this case is [1]:

$$\Delta P = 3 \cdot \left(R_{f1} \cdot I_1^2 + \sum_{k=2}^{n} R_{fk} \cdot I_k^2 \right) \qquad (2)$$

where R_{fk} is the line resistance corresponding to the frequency of *k-th* harmonic, and I_k is the effective value of the correspondent current.

The mathematical relationship for power losses in LV lines with four conductors functioning in sinusoidal unbalanced state is [1; 2] is:

$$\Delta P = (I_1^2 + I_2^2 + I_3^2) \cdot R_f + I_N^2 \cdot R_N. \qquad ...(3)$$

During non-sinusoidal and unbalanced operating state, through each active conductor flows a real current that includes the fundamental component and the harmonic content. Power losses calculus is made using the following relationship:

$$\Delta P_{total} = \sum_{i=A,B,C,N} \Delta P_i \quad [W], \qquad ...(4)$$

where $\Delta P_i = \sum_{k=1}^{n} R_f \cdot I_{ki}^2\ [W]$ represents power losses in phase A,B,C and neutral conductor;…(5)

In the relationships (1) – (5), ΔP represents total power losses [W], I is current's r.m.s. value in sinusoidal balanced state, R_f - phase conductors' resistance [Ω]; R_N - neutral conductor's resistance [Ω], while $I_{kA}, I_{kB}, I_{kC}, I_{kN}$ represent the effective values of harmonic currents for each phase, and for the neutral conductor, respectively [A].

If the losses obtained with (4) are referred to the losses considered in a balanced and sinusoidal state, the value of the supplementary relative power losses is obtained as:

$$\varepsilon_{\Delta P} = \frac{\Delta P_{total} - \Delta P_1}{\Delta P_1} \cdot 100\ [\%], \qquad …(6)$$

where $\Delta P_1, \Delta P_{total}$ represent the power losses in balanced and sinusoidal state, and in unbalanced and non-sinusoidal state, respectively [1, 3, 4].

For the unbalanced sinusoidal state, the supplementary relative power losses can be calculated as [5]:

$$\varepsilon_{\Delta P} = k_I^{-2} + k_I^{0 2} \cdot (1 + 3 \cdot \frac{R_N}{R_f}), \qquad (7)$$

where k_I^- is the negative unbalance factor of the line currents, while k_I^0 is the zero unbalance factor of the currents. The dependence of these losses on the unbalance factors is depicted in Figure 1.

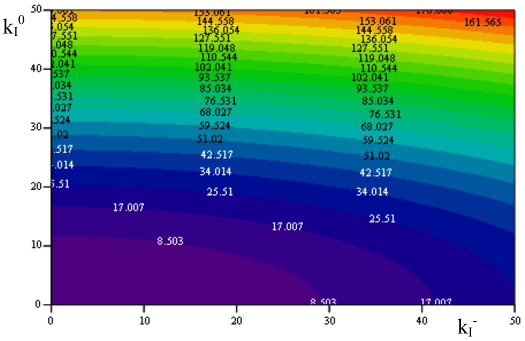

Figure 1. The variation of supplementary relative power losses – unbalance state

During non-sinusoidal balanced state, current harmonics can be divided in three categories: *3k*, *3k+1* and *3k+2* order harmonics. Calculus of supplementary relative power losses as a function of current total harmonic distortion factor is performed by the following mathematical relationship:

$$\varepsilon_{\Delta P} = THD_I^{\ 2} + \frac{R_N}{R_f} \cdot \frac{\sum I_{3k}^{\ 2}}{I_1^{\ 2}}; \qquad ...(8)$$

where THD_I is the current total harmonic distortion factor, and I_{3k} represent 3*k* order harmonic currents. The variation of relative power losses is presented in Figure 2.

3. STUDY CASE

The expansion of modern cities leads to electric distribution grids that supply an increasing number of domestic consumers. These consumers include domestic appliances that are important harmonic sources and also produce the unbalance of the line current system.

Analyze of power losses in an urban distribution electric grid was performed on the electric system presented in Figure 3. The distribution grid supplies an assembly of blocks of flats and has the following technical parameters:

- Electric cables 3x240 + 120 mm^2, length L = 30 m, that connects the substation and the PCC;
- Electric cables ACYABY 3x150 + 70 mm^2, length L = 300 m, that supply the block of flats.

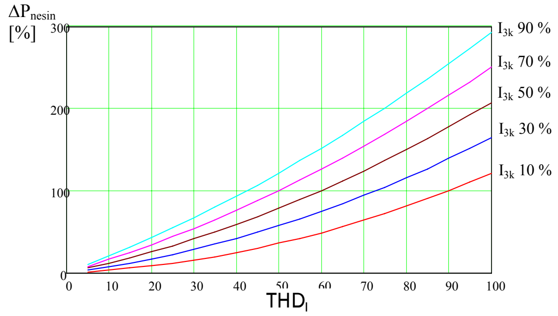

Figure 2. Supplementary relative power losses as a function of THD_I and weight of I_{3k} order currents

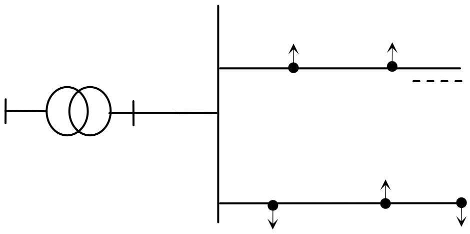

Figure 3. Radial urban electric distribution network

Measurements have been performed at the LV bus bars of the substation for a period of 24 hours, using a Memobox meter. The values were acquired every 10 minutes, in accordance with the actual standards.

The experimental data show an unbalanced and non-sinusoidal working state, but the power quality indicators do not exceed the limits foreseen in the actual Romanian standards. To highlight the influence of pollution level over the power losses, three cases were considered: sinusoidal unbalanced, balanced non-sinusoidal and unbalanced non-sinusoidal.

A. *Balanced non-sinusoidal operating state*

The level of harmonic pollution was assessed by the total harmonic distortion factor; its variation is shown in Figure 4.

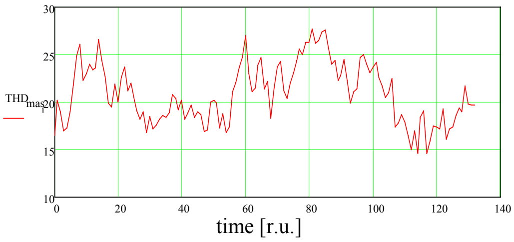

Figure 4. Time variation of current total harmonic factor

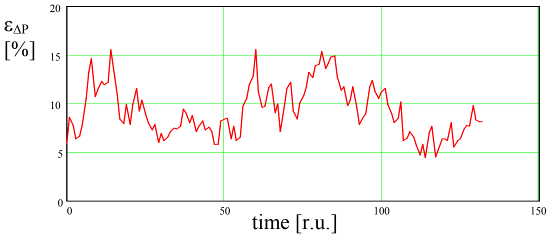

Figure 5. Time variation of relative power losses in non-sinusoidal state

Figure 5 depicts the supplementary relative power losses calculated with (9), but the skin effect is not taken into consideration.

B. *Sinusoidal unbalanced operating state*

The unbalance level is expressed by the unbalance factors presented in Figures 6,a and b; the variation in time of supplementary power losses is underlined in Figure 7.

C. *Real operating state*

During the real functioning state (unbalanced and non-sinusoidal), the pollution level is the highest one, and so are its effects. In order to calculate the supplementary power losses, only the even harmonics up to 13th rank and the skin effect were taken in consideration. The values of line and neutral conductors' resistance, for different frequencies are presented in Table, while the variation of supplementary losses for the survey period is presented in Figure 8.

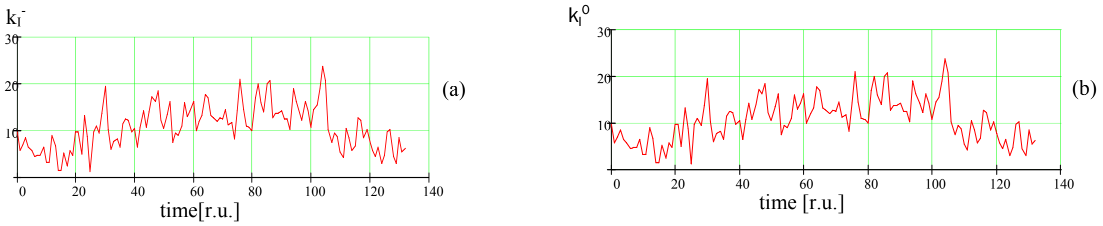

Figure 6. Time variation of negative (a) and zero (b) unbalance factors

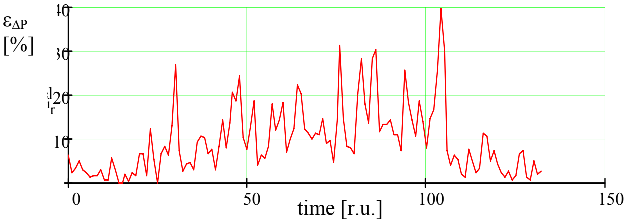

Figure 7. Time variation of relative power losses in an unbalanced state

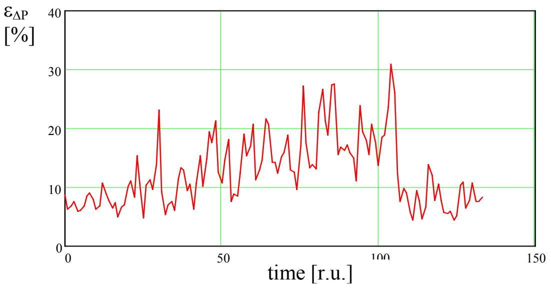

Figure 8. Time variation of relative power losses in the real operating state

Table 1. Electric conductors' resistance depending on the harmonic rang

Harmonic rank	1	3	5	7	9	11	13
Line conductors resistance R_f [Ω]	0.059	0.06	0.062	0.064	0.068	0.071	0.075
Neutral conductor resistance R_n [Ω]	0.126	0.127	0.127	0.129	0.131	0.133	0.135

4. CONCLUSIONS

The LV modern distribution grids supply a great number of domestic consumers that introduce in the system harmonic and unbalanced currents. These currents establish a permanent unbalanced and non-sinusoidal operating state. An important consequence of this situation is the growth of power losses in all networks' elements.

Following the study case performed on a typical urban distribution grid, it was established that:

- the values of power quality factors for unbalance and harmonic disturbances do not exceed the normal standards considered in the actual norms;
- during the non-sinusoidal state, a mean value of the total harmonic distortion factor of 20,86 % can produce supplementary power losses of 10,45 %;
- during the unbalanced state, a mean unbalance factor of 10 % can determine the growth of power losses by 11 %;
- a very important percentage of these losses are caused by currents that flow through the neutral conductor;
- the supplementary power losses grow alarming, exceeding in some periods of time even 20%, but in general they are 14 %.

5. REFERENCES

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